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Faruquee et al.

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(54) **FAN SHROUD**

(71) Applicant: **Deere & Company**, Moline, IL (US)

(72) Inventors: **Zakir Faruquee**, Asbury, IA (US); **Erik Holzhuter**, Dubuque, IA (US); **Mike P. Faust**, Garber, IA (US); **Luke Longhenry**, Cuba City, WI (US); **Joel Khristy**, Naperville, IL (US)

(73) Assignee: **DEERE & COMPANY**, Moline, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(51) **Int. Cl.**

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F01P 5/06	(2006.01)
F01P 11/10	(2006.01)

(52) **U.S. Cl.**

CPC ***F04D 29/545*** (2013.01); ***F01P 5/06*** (2013.01); ***F01P 11/10*** (2013.01)

(58) **Field of Classification Search**

CPC F04D 29/552; F04D 29/545; F04D 29/547; F04D 29/663; F04D 29/665; F04D 29/667; F01P 5/05; F01P 11/10

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,794,001	A *	2/1974	Birch	F04D 29/164	123/41.05
3,858,644	A *	1/1975	Beck	F01P 5/06	165/51
5,489,186	A *	2/1996	Yapp	F01D 5/141	415/208.3
6,676,371	B1 *	1/2004	Brown	F04D 29/023	123/41.49
9,157,455	B2 *	10/2015	Bilodeau	F04D 29/663	
10,041,505	B2 *	8/2018	Stevens	F04D 29/526	

(Continued)

FOREIGN PATENT DOCUMENTS

CN	204880603 U	12/2015
DE	102015224344 A1	6/2017

(Continued)

OTHER PUBLICATIONS

John Deere, “Shroud Part No. T294150 for 332E Skid Steer Loader,” <https://partscatalog.deere.com/jdrc/sidebyside/equipment/63109/referrer/search/pgId/6850056>, web page publicly available at least as early as Feb. 18, 2019.

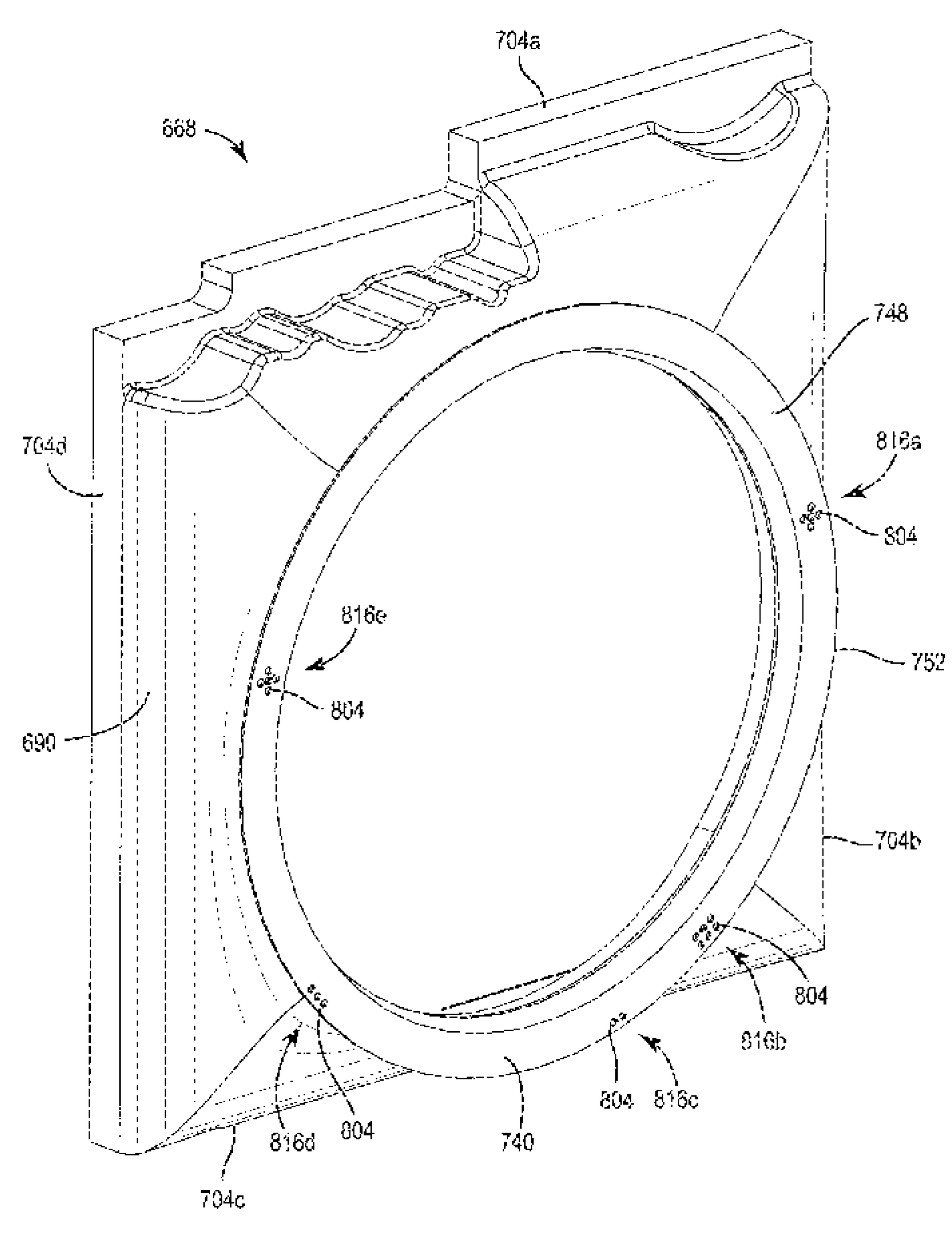
(Continued)

Primary Examiner — Nathaniel E Wiehe
Assistant Examiner — Ryan C Clark
(74) *Attorney, Agent, or Firm* — Michael Best & Friedrich LLP

(57) **ABSTRACT**

A shroud for a cooling fan that is being positionable within the chassis of an off-highway machine. The shroud includes an inlet, an outlet, an elliptical lip section positioned adjacent to the outlet, and a plurality of apertures extending through the elliptical lip section. Each aperture of the plurality of apertures is positioned greater than 10 degrees away from an adjacent aperture of the plurality of apertures.

11 Claims, 20 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

10,072,670	B2 *	9/2018	Jung	F04D 29/526
2008/0219836	A1	9/2008	Decker et al.	
2017/0350412	A1 *	12/2017	Hioki	F04D 29/164

FOREIGN PATENT DOCUMENTS

EP	3073121	A1	9/2016
WO	WO2018072664	A1	4/2018

OTHER PUBLICATIONS

John Deere, "Shroud Part No. AT447978 for 437E Knuckleboom Log Loader," <https://partscatalog.deere.com/drc/sidebyside/equipment/81754/referrer/search/pgId/237522305>, web page publicly available at least as early as Feb. 18, 2019.

John Deere, "Shroud Part No. T397959 for E140LC Excavator," <https://partscatalog.deere.com/jdrc/sidebyside/equipment/1345789/referrer/search/pgId/217542605/partnumber/T397959/callout/22>, web page publicly available at least as early as Feb. 18, 2019.

John Deere, "Shroud Part No. T352549 for WL56 Loader," <https://partscatalog.deere.com/jdrc/sidebyside/equipment/68898/referrer/search/pgId/154027016>, web page publicly available at least as early as Feb. 18, 2019.

John Deere, "Shroud Part No. AT425301 for 710L Backhoe Loader," <https://partscatalog.deere.com/jdrc/sidebyside/equipment/171246/referrer/search/pgId/265599467/partnumber/AT425301/callout/1>, web page publicly available at least as early as Feb. 18, 2019.

John Deere, "Shroud Part No. T368719 for E260LC Excavator," <https://partscatalog.deere.com/jdrc/sidebyside/equipment/613564/referrer/search/pgId/212925555>, web page publicly available at least as early as Feb. 18, 2019.

John Deere, "Shroud Part No. AT455495 for 853M Tracked Feller Buncher," <https://partscatalog.deere.com/drc/sidebyside/equipment/65533/referrer/search/pgId/285028132/partnumber/AT455495/callout/1>, web page publicly available at least as early as Feb. 18, 2019.

European Search Report issued in counterpart application No. 20163174.4 dated Jul. 17, 2020 (08 pages).

* cited by examiner

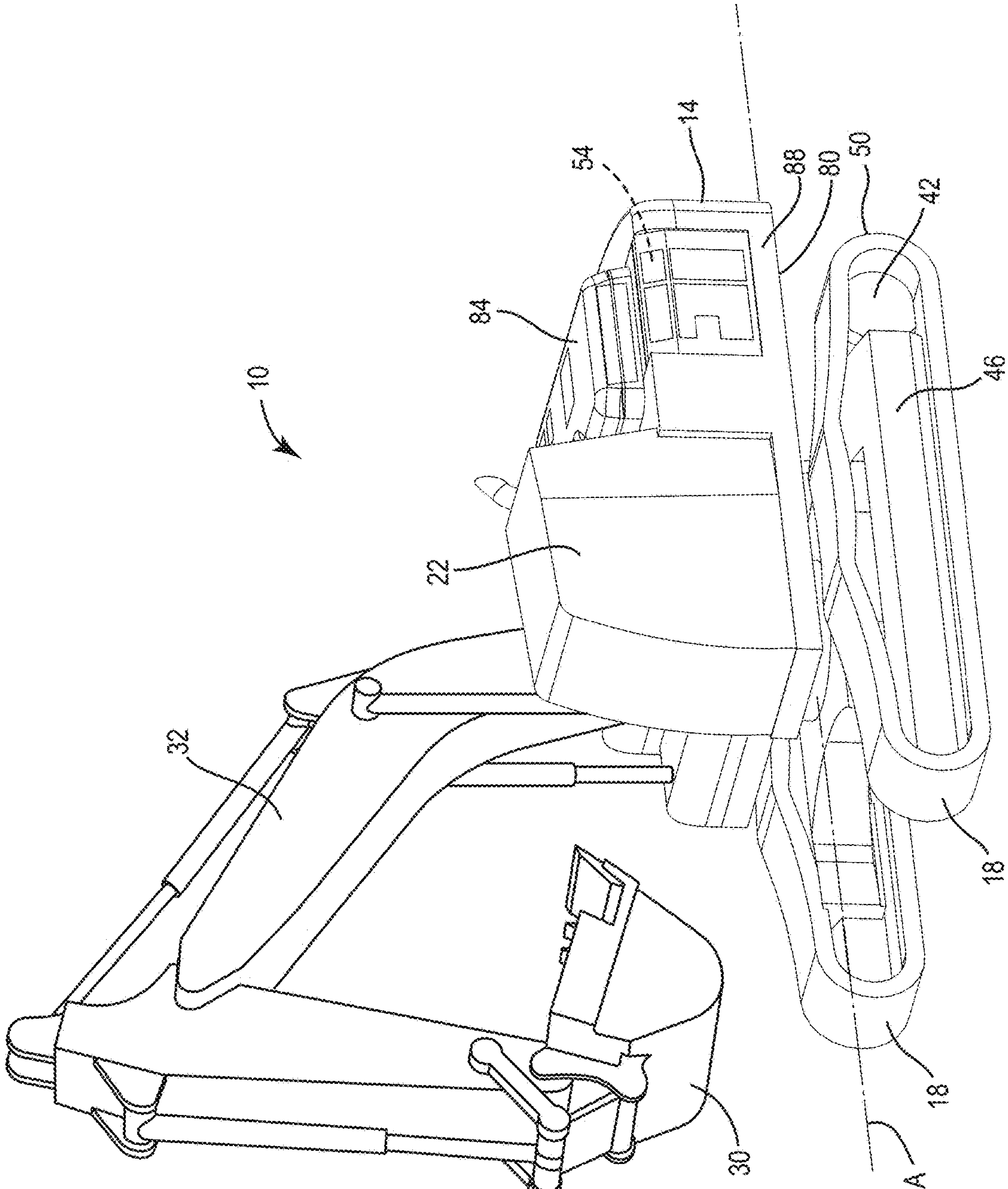


Fig. 1

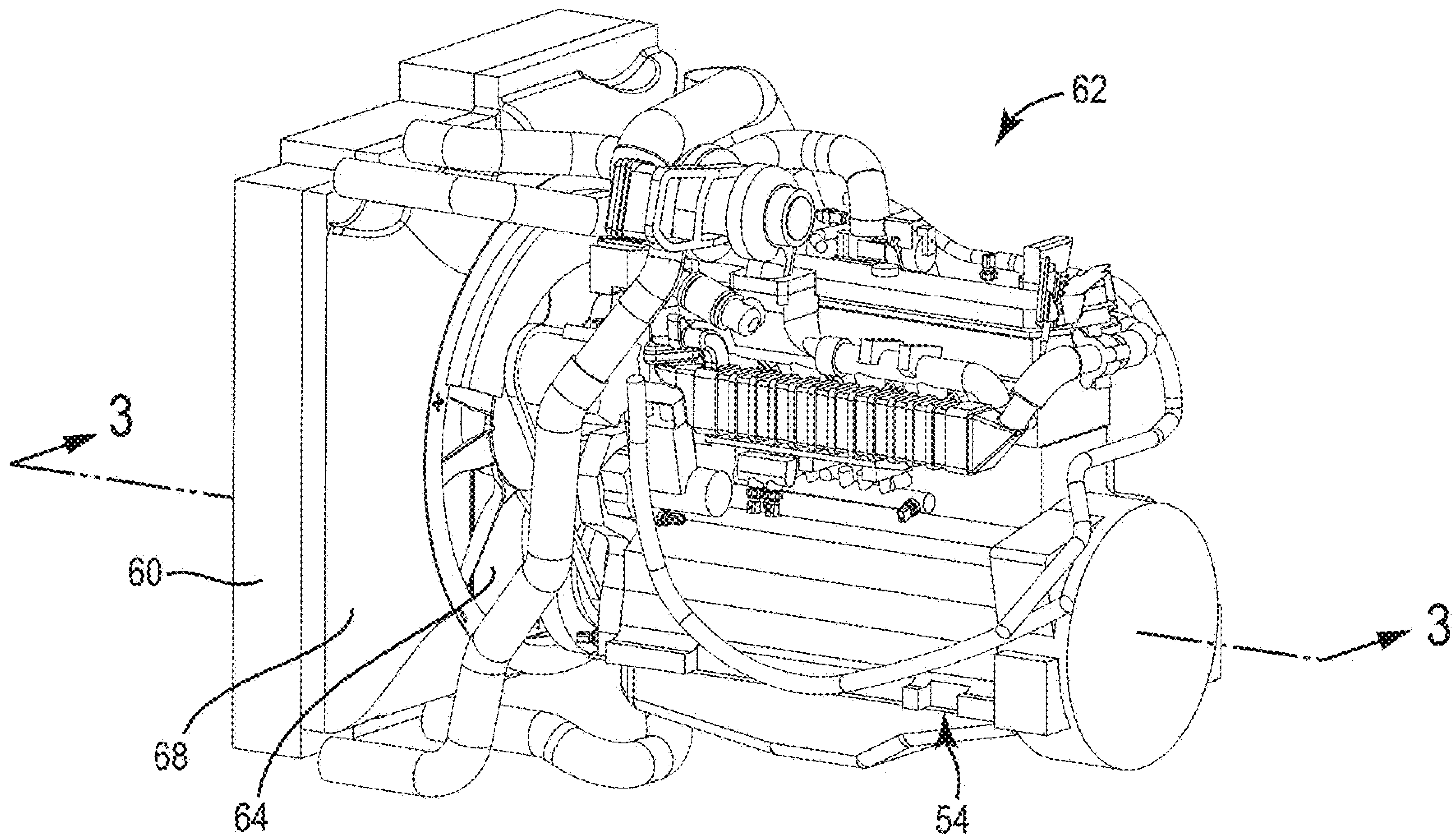


FIG. 2

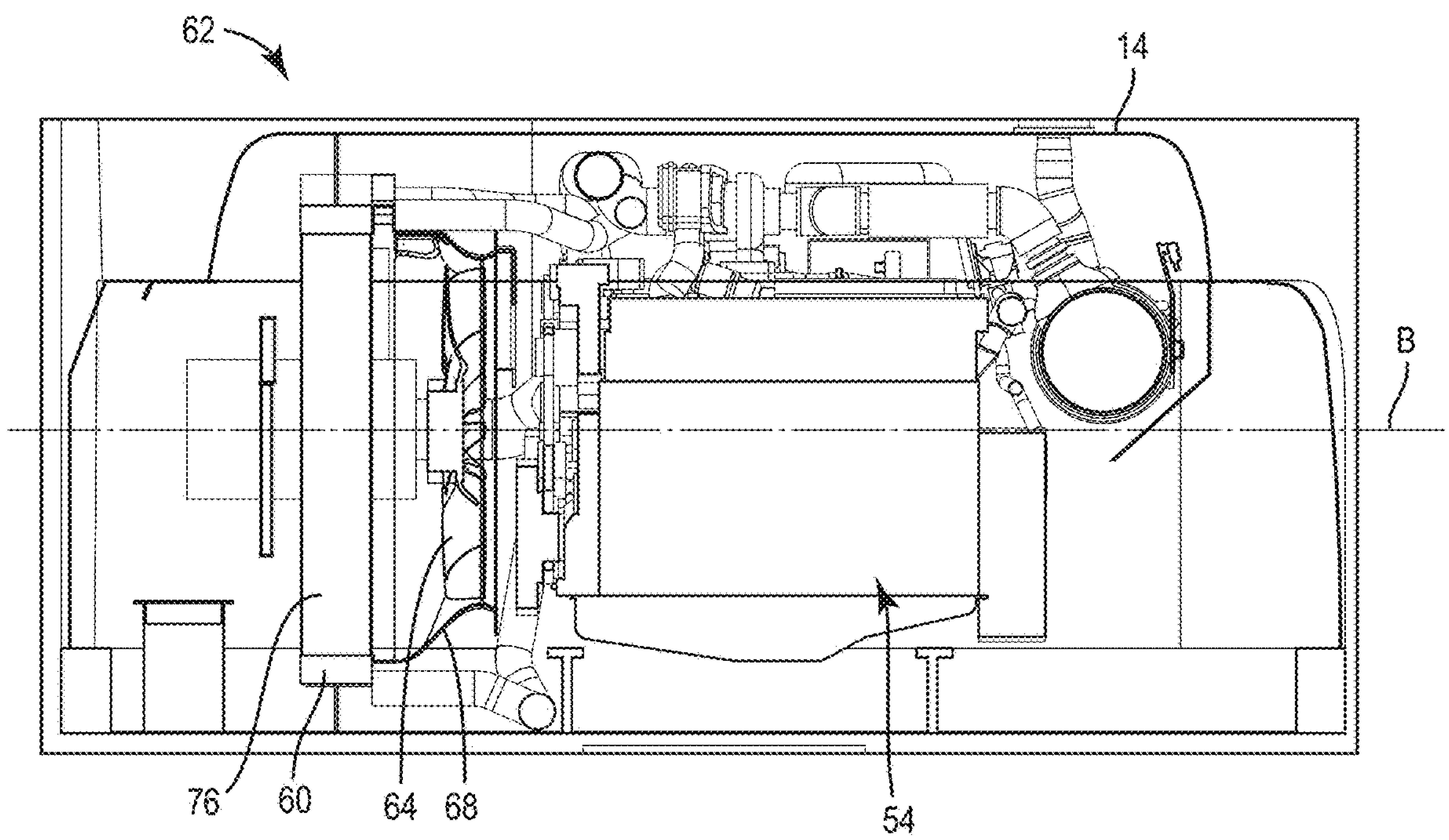


FIG. 3

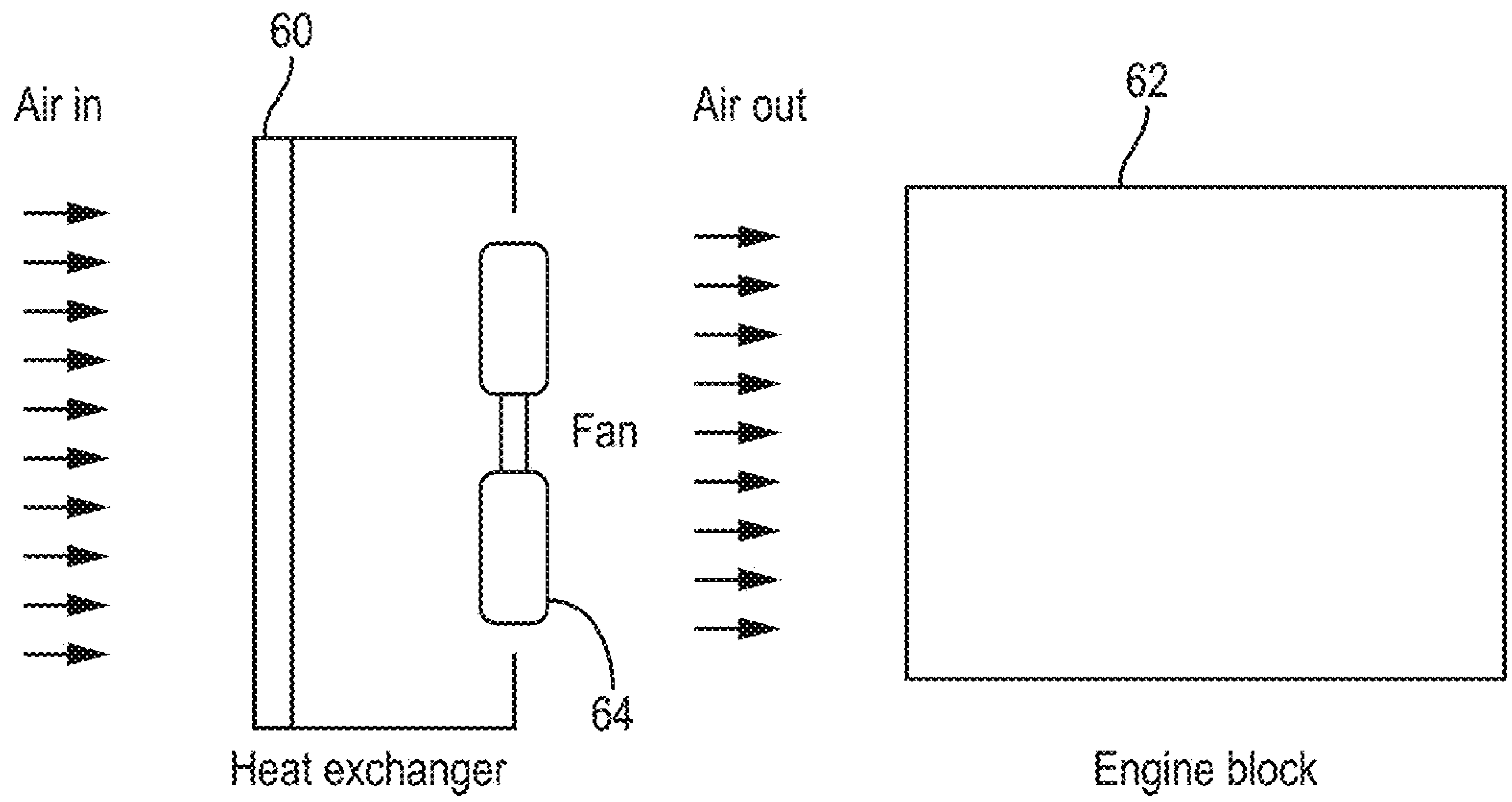

60
Air in
Air out
62
Fan
64
Heat exchanger
Engine block

FIG. 4

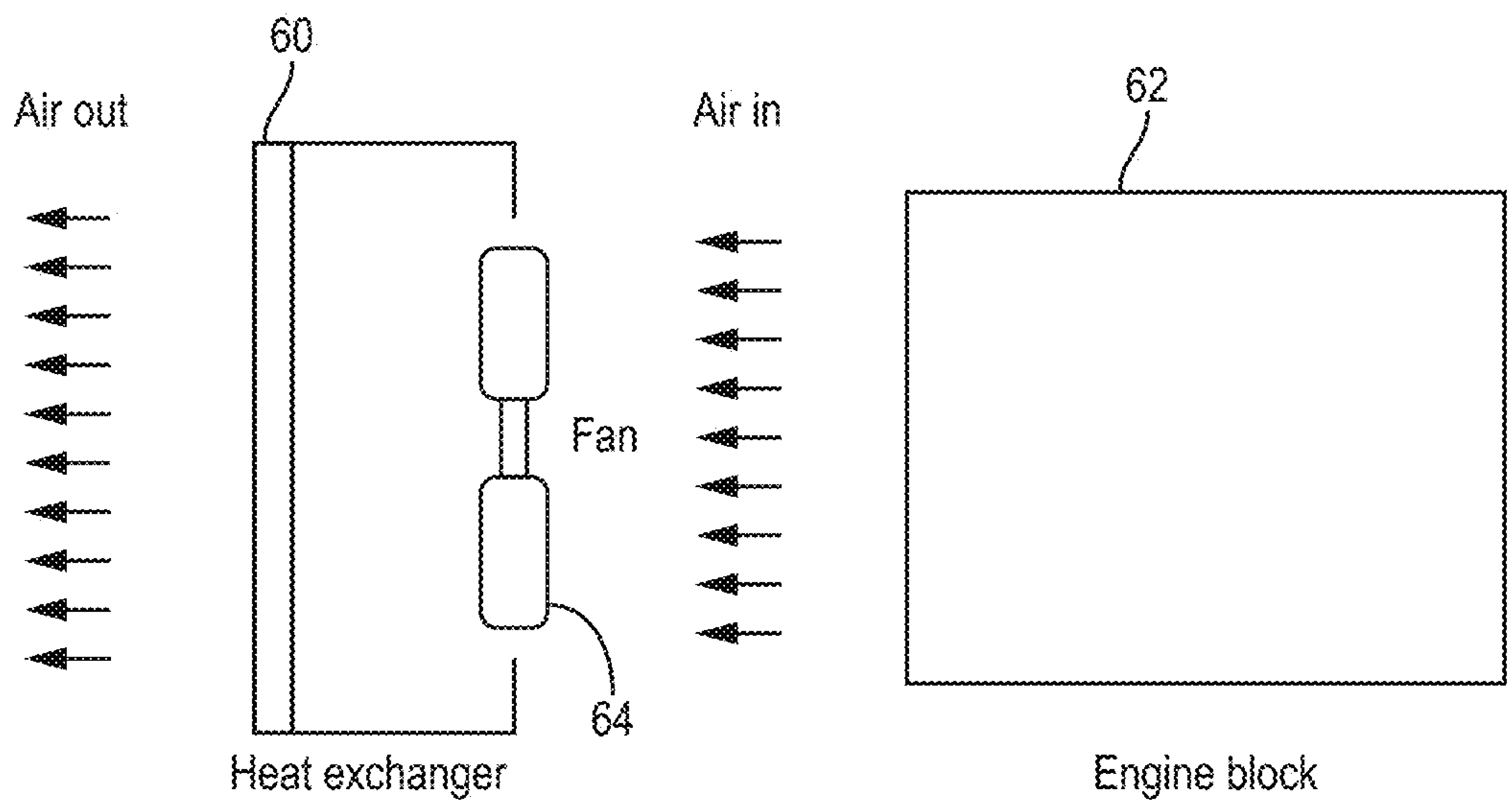

60
Air out
Air in
62
Fan
64
Heat exchanger
Engine block

FIG. 5

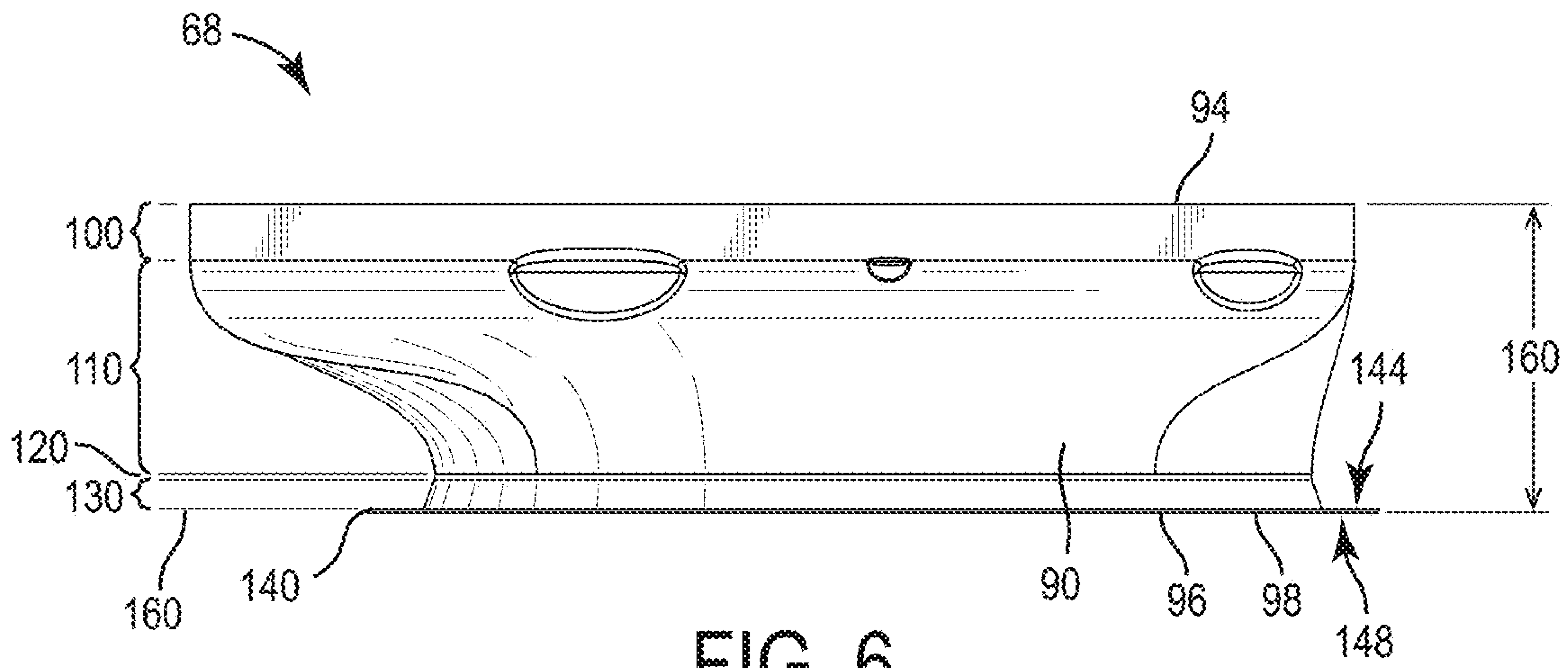

68
94
100
110
120
130
160
144
140
90
96
98
148

FIG. 6

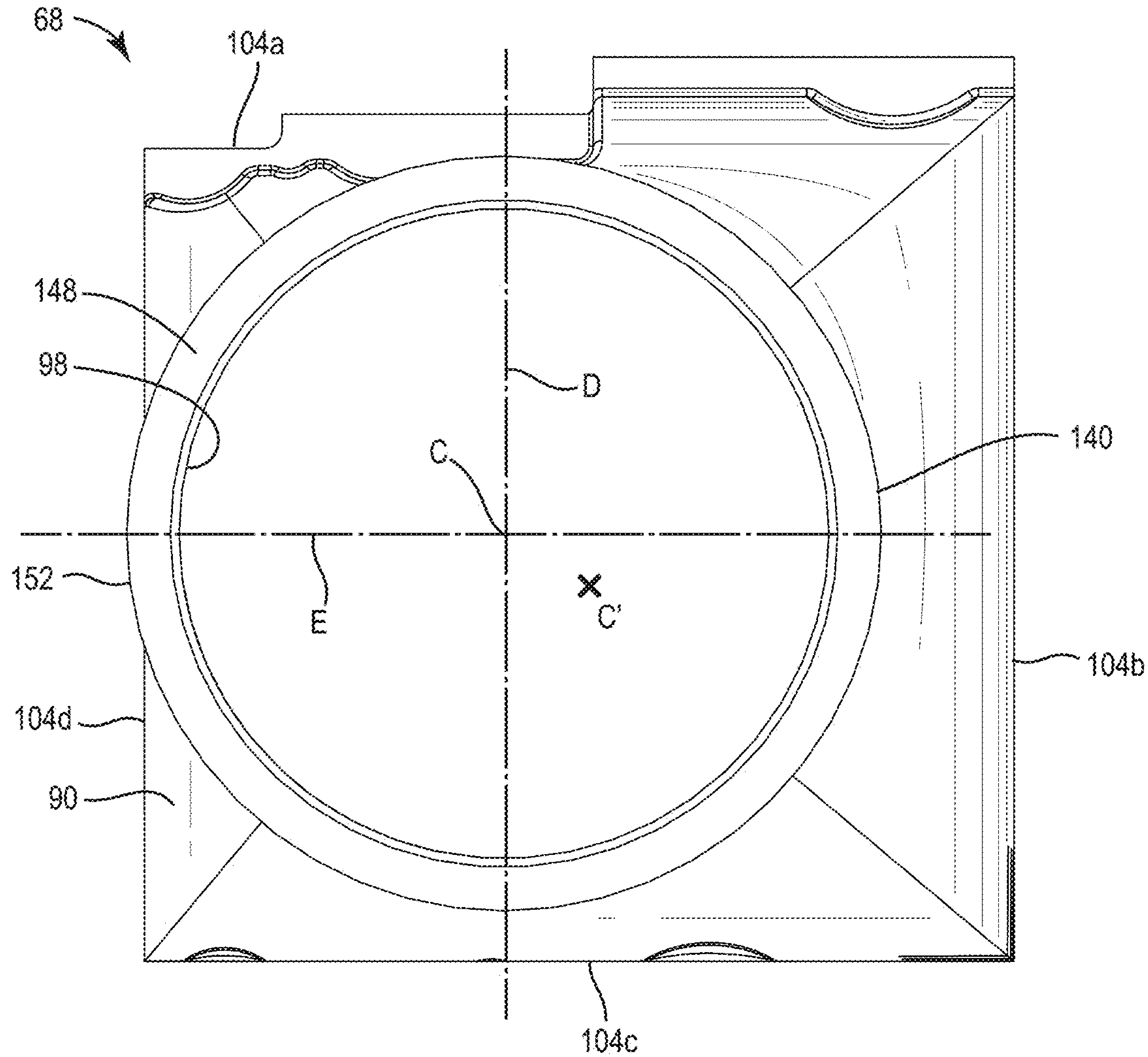

68
104a
148
98
D
C
140
152
E
C'
104b
104d
90
104c

FIG. 7

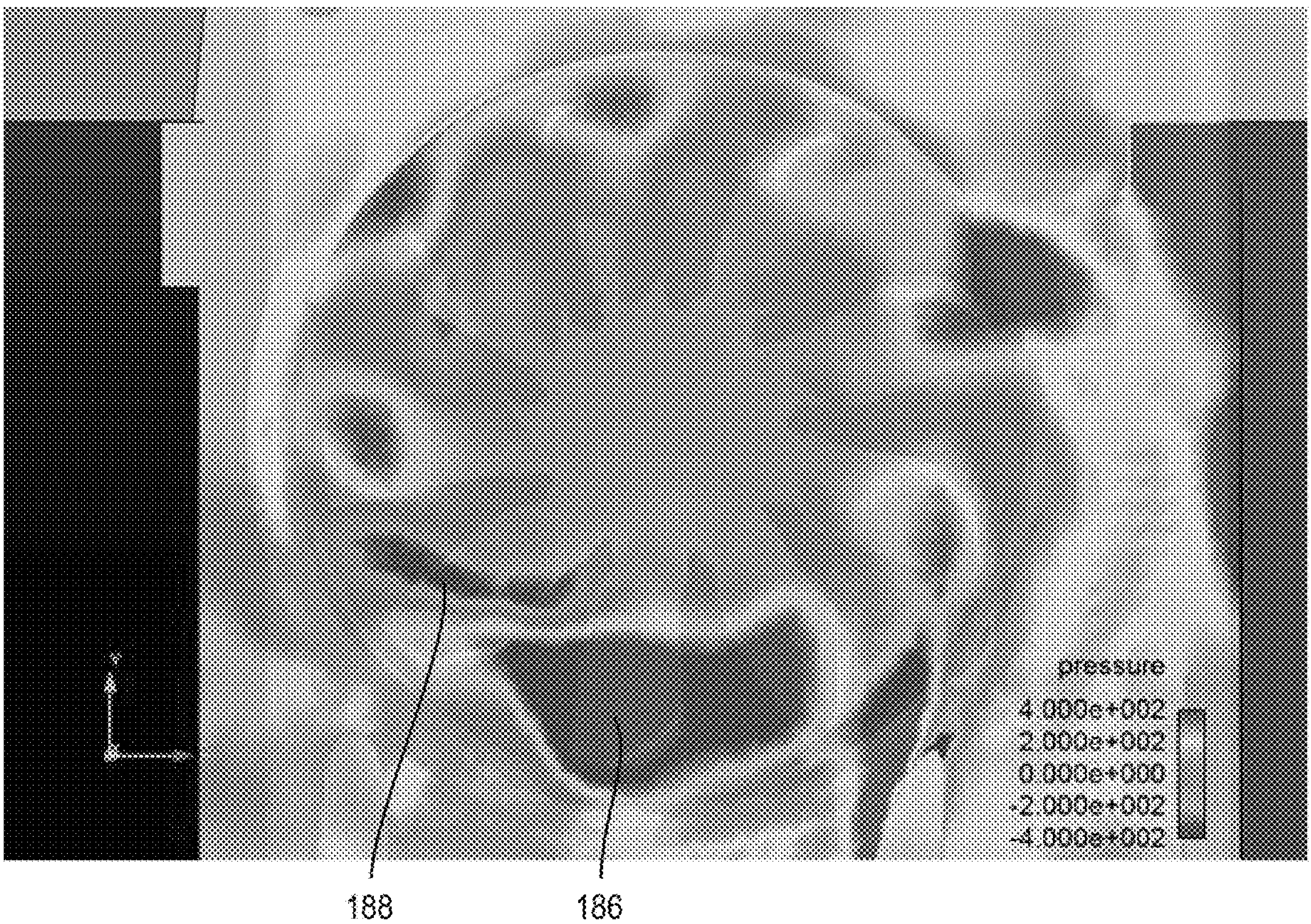

pressure
4.000e+002
2.000e+002
0.000e+000
-2.000e+002
-4.000e+002
188
186

FIG. 8

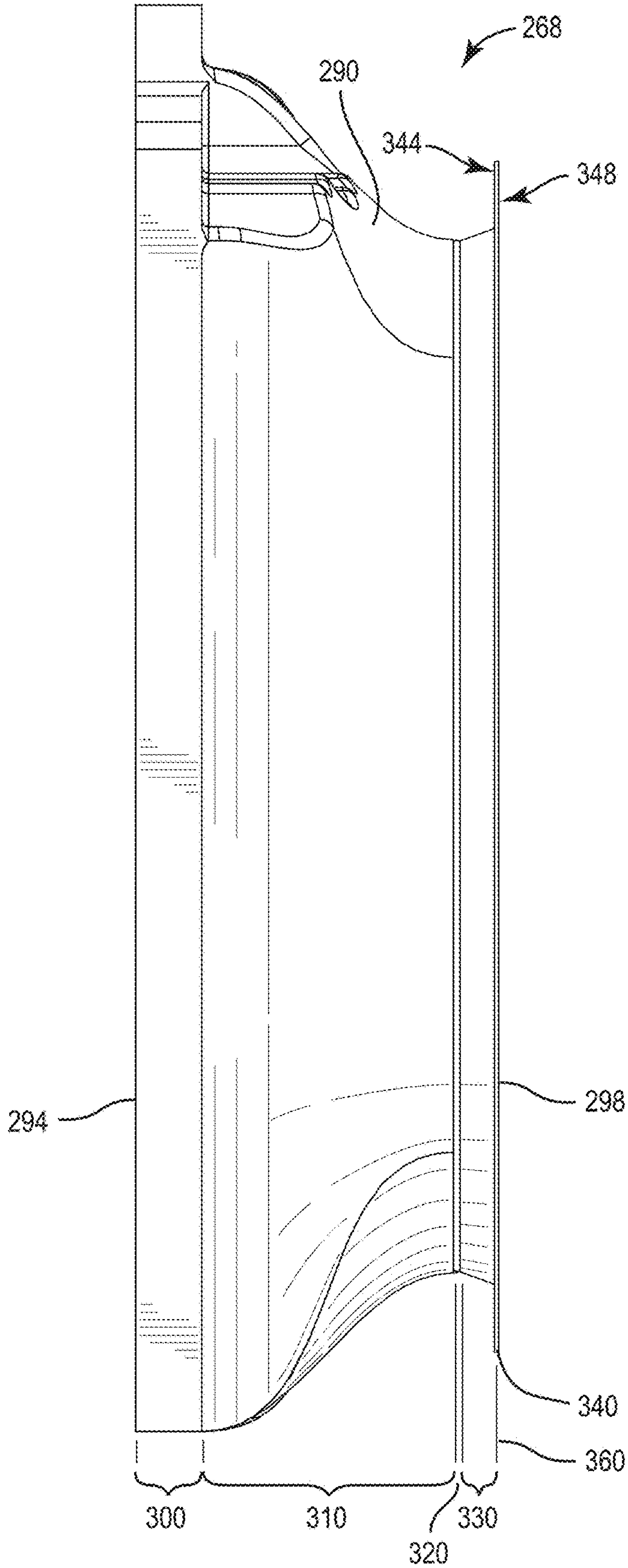


FIG. 9

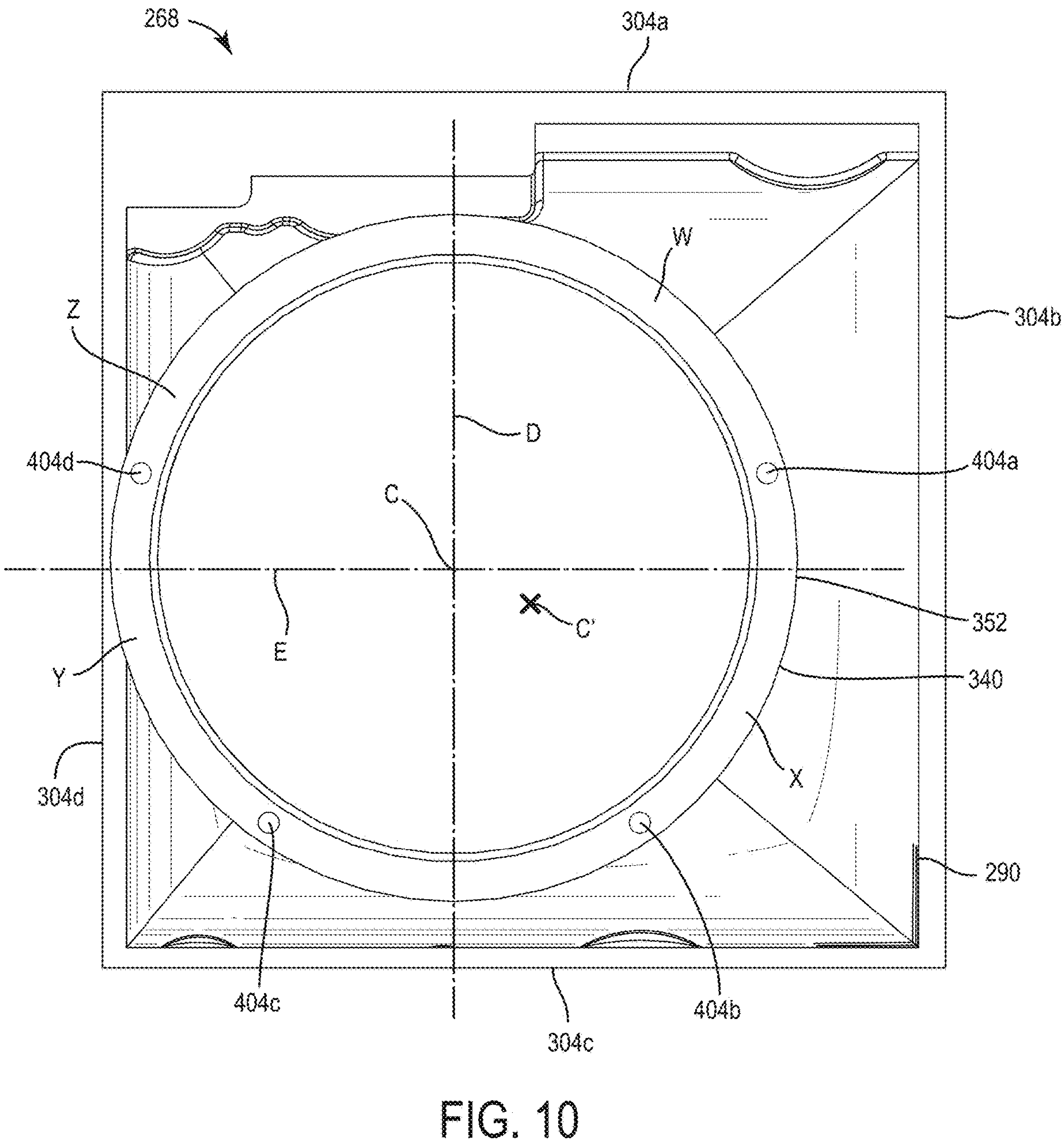

268
304a
304b
W
Z
D
404d
404a
C
C'
E
352
Y
340
304d
X
290
404c
404b
304c

FIG. 10

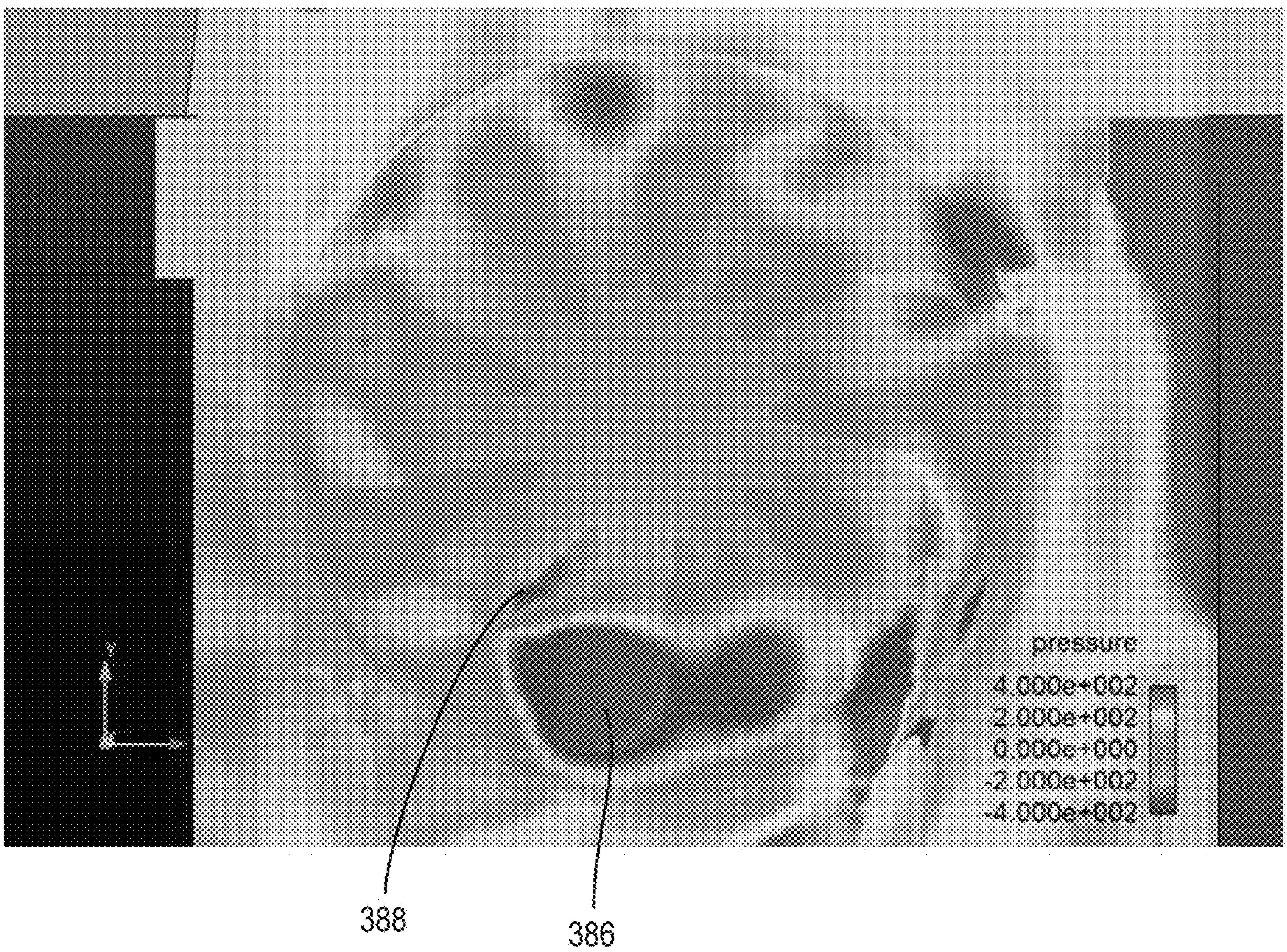

pressure
4.000e+002
2.000e+002
0.000e+000
-2.000e+002
-4.000e+002
388
386

FIG. 11

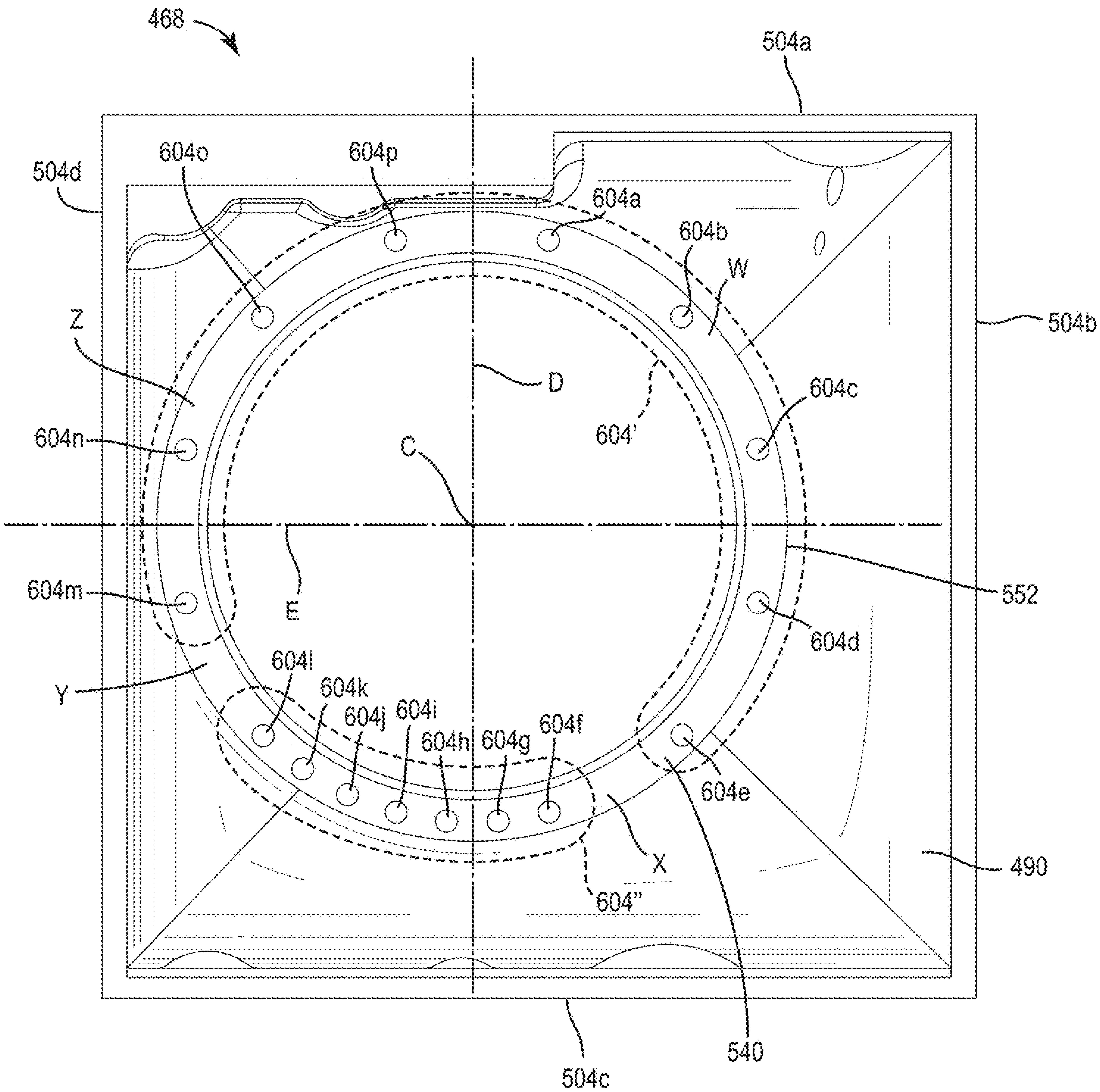

468
504a
504d
504b
504c
604o
604p
604a
604b
W
Z
D
604c
604'
604n
C
604m
E
552
604d
Y
604l
604k
604j
604i
604h
604g
604f
604e
X
604"
490
540

FIG. 12

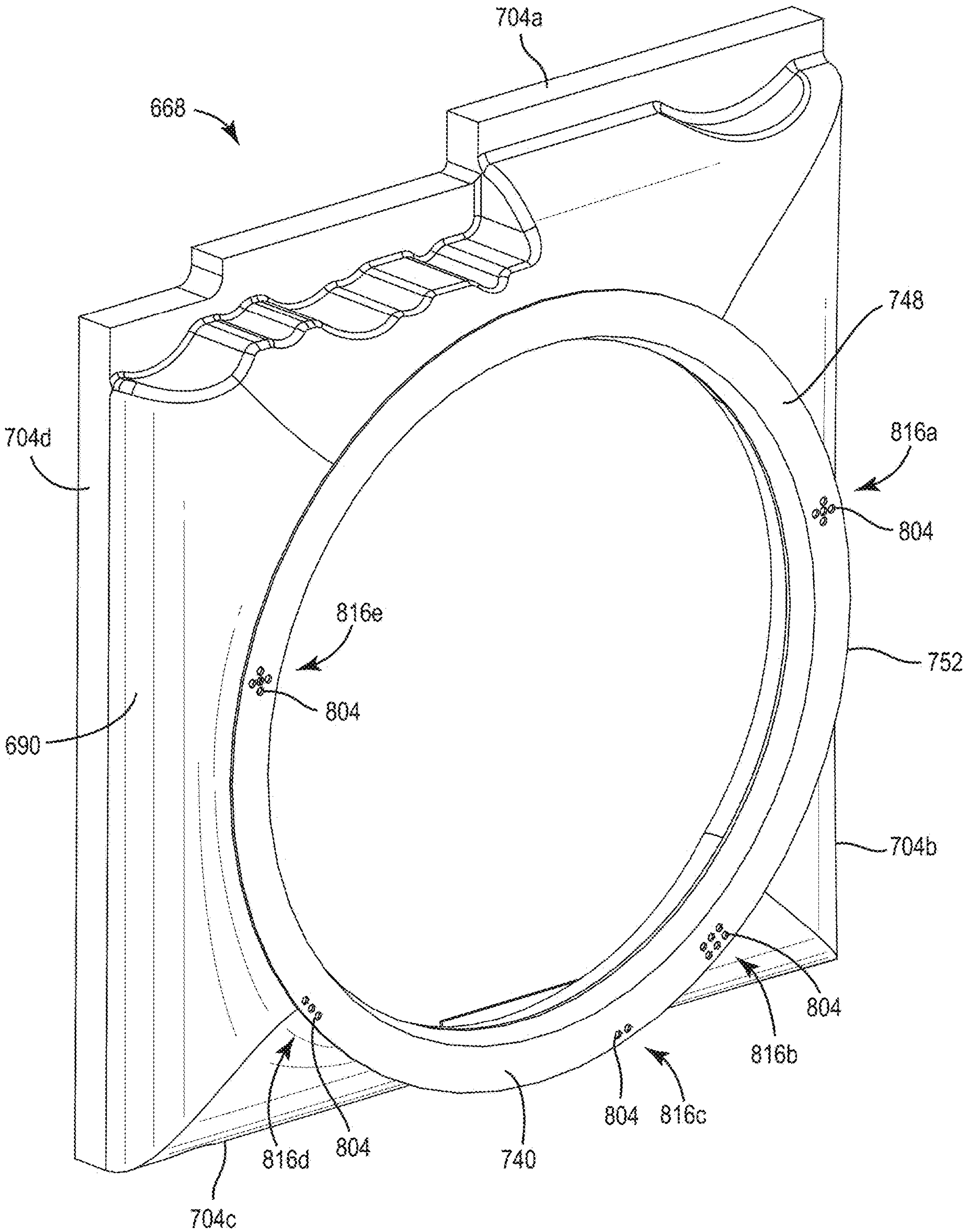

704a
668
748
704d
816a
804
816e
752
804
690
704b
804
804
816b
804
816c
816d
804
740
704c

FIG. 13

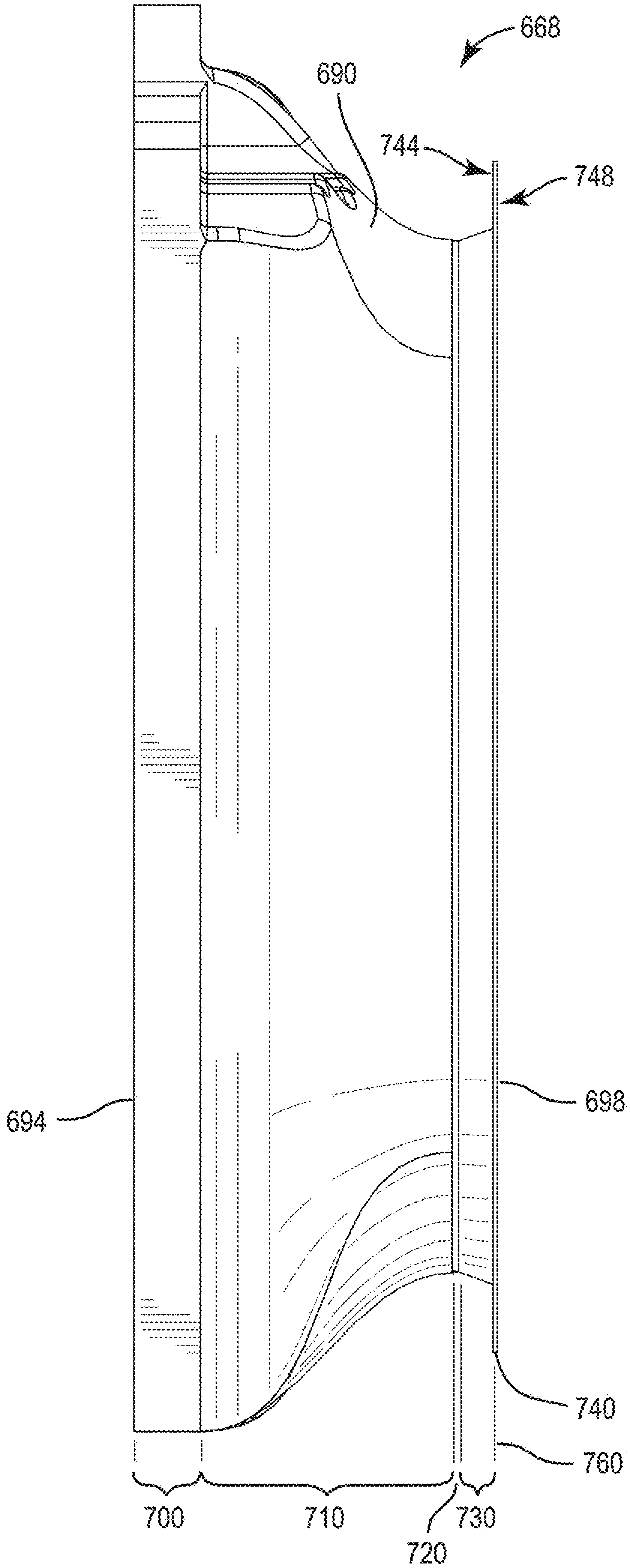


FIG. 14

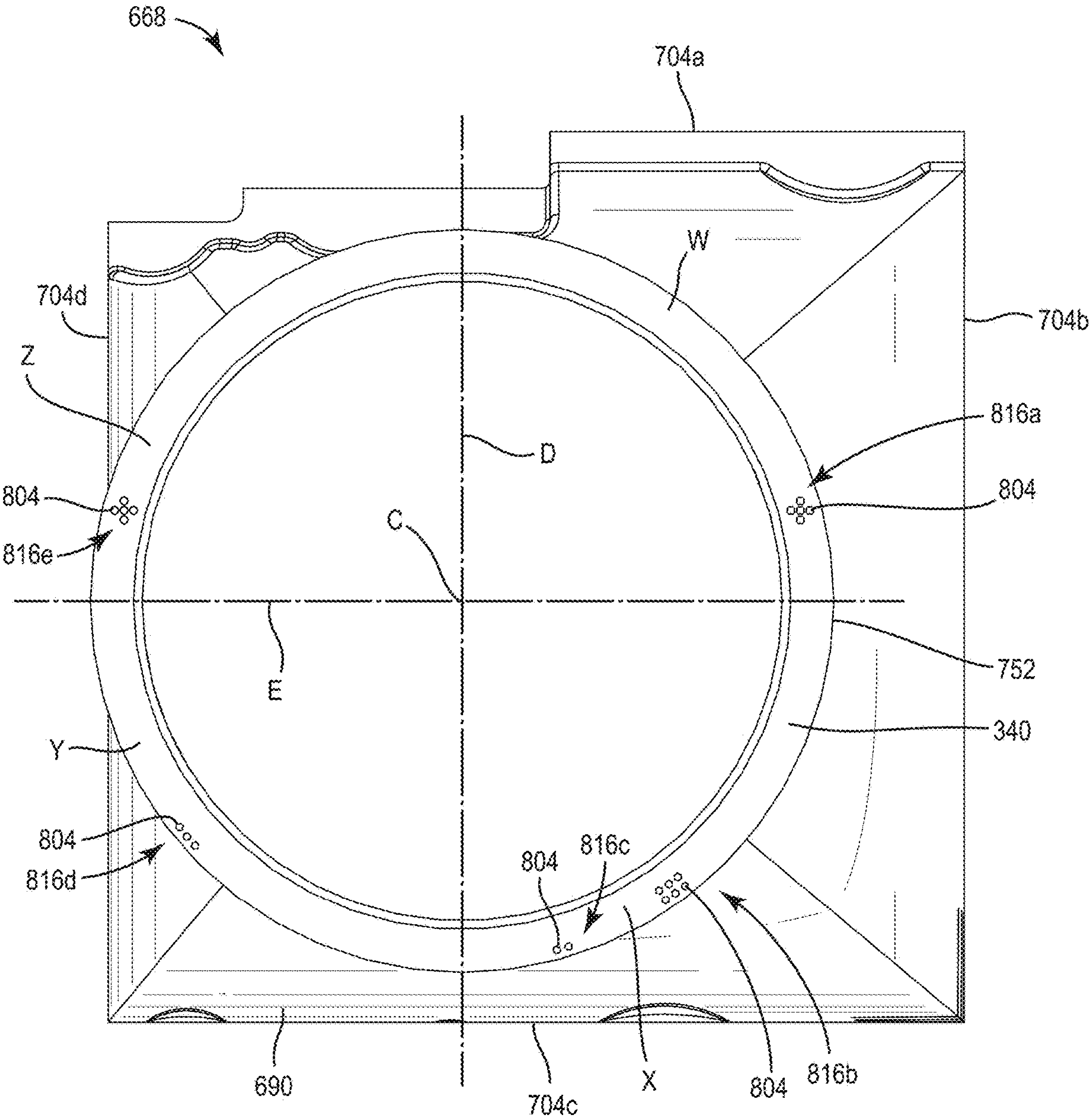

668
704a
704b
704d
W
Z
D
816a
804
804
C
816e
752
E
340
Y
804
816c
804
816d
690
704c
X
804
816b

FIG. 15

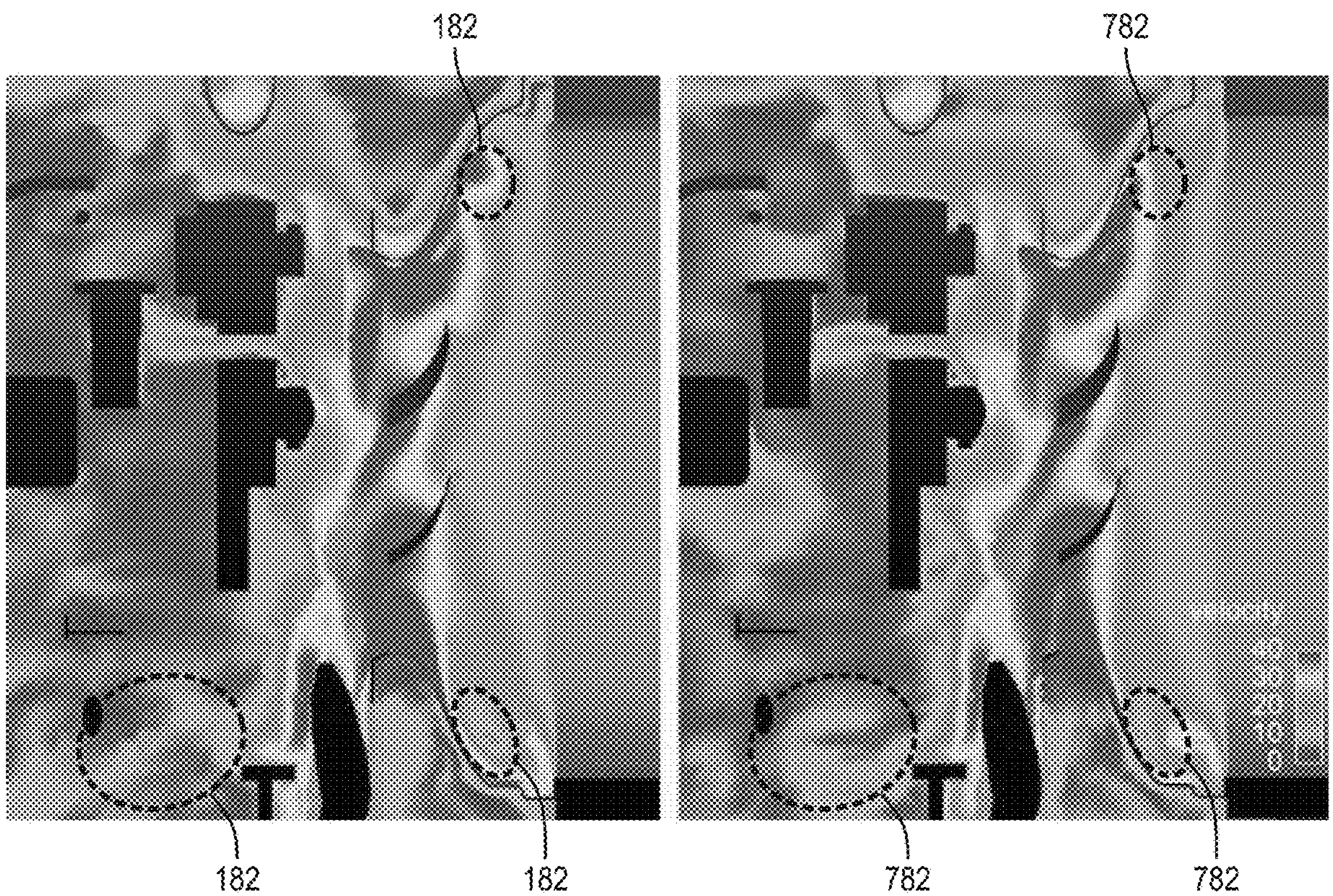


FIG. 16

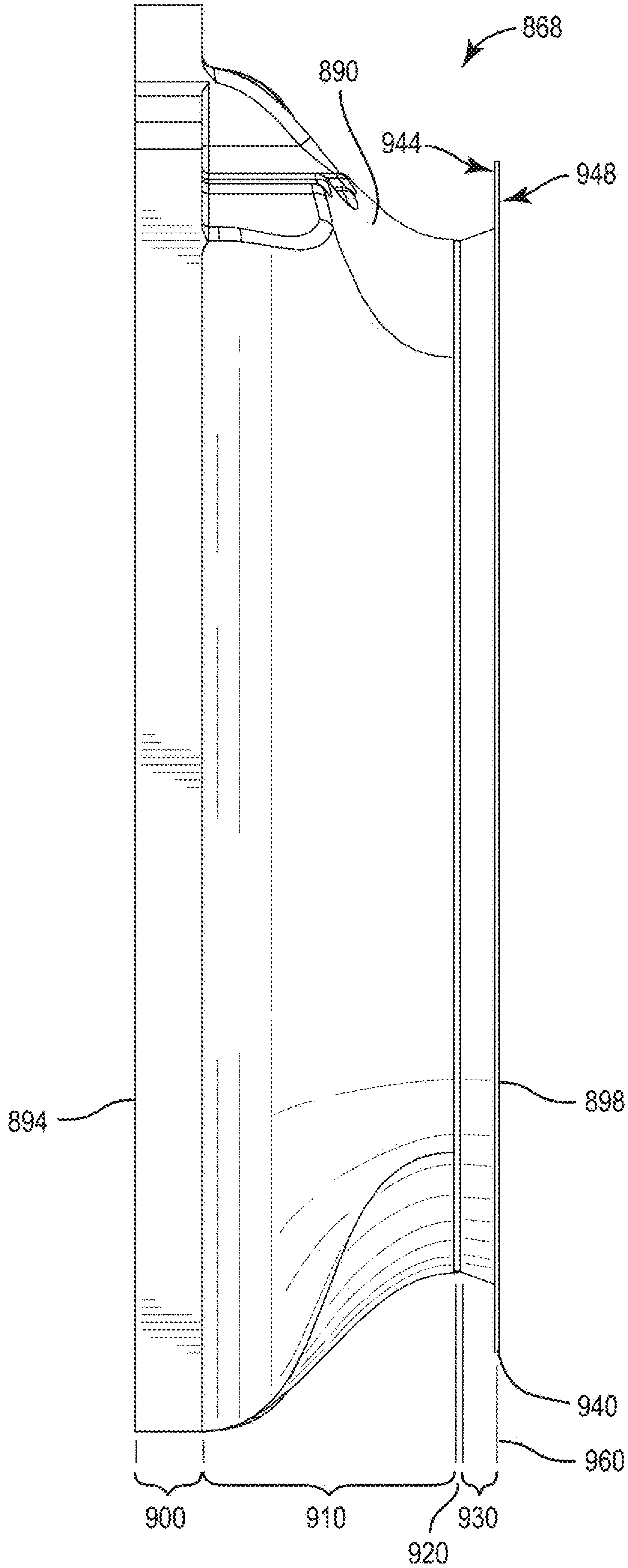


FIG. 17

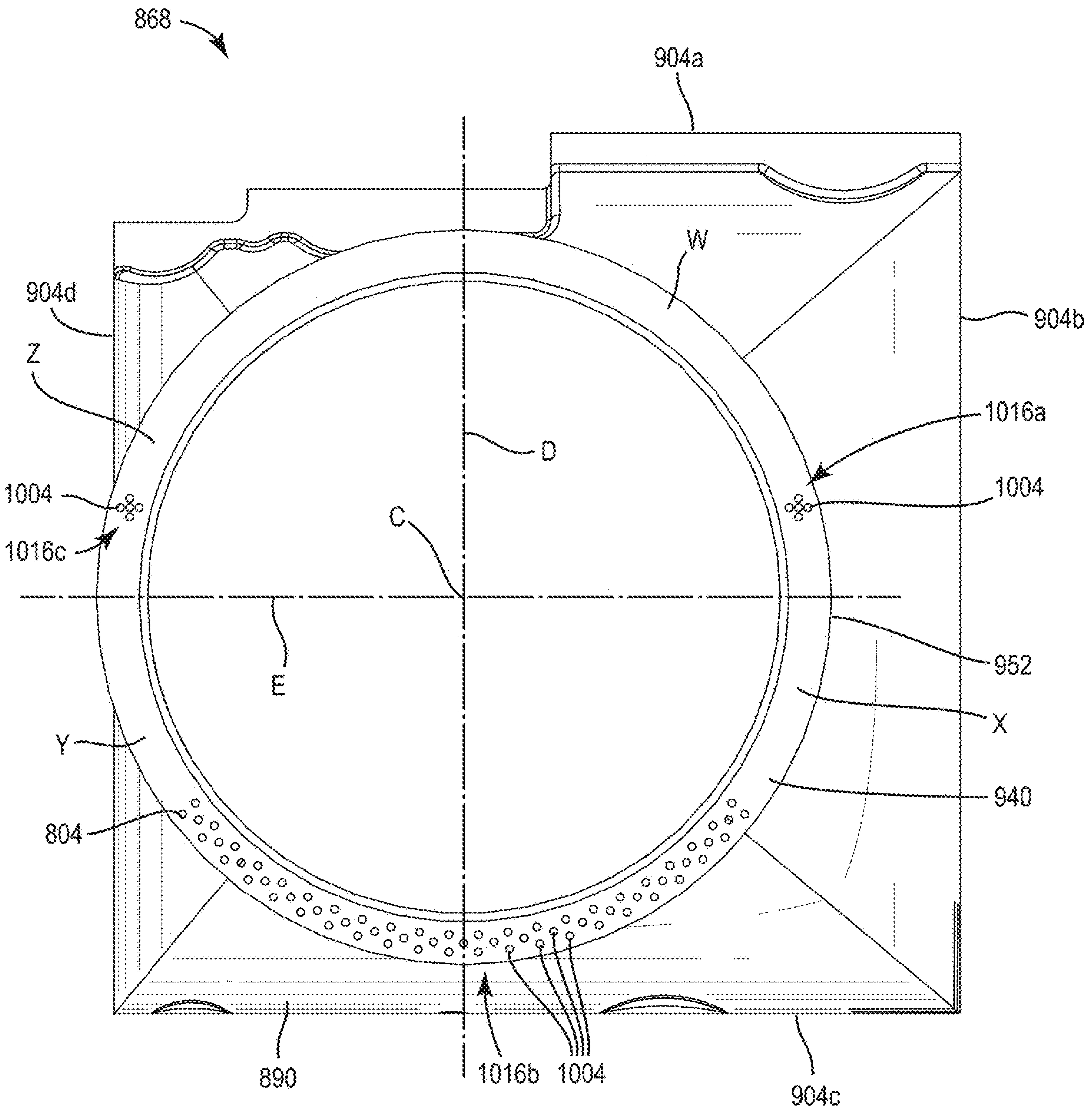

868
904a
W
904d
904b
Z
1016a
D
1004
1004
C
1016c
952
E
X
Y
940
804
890
1016b
1004
904c

FIG. 18

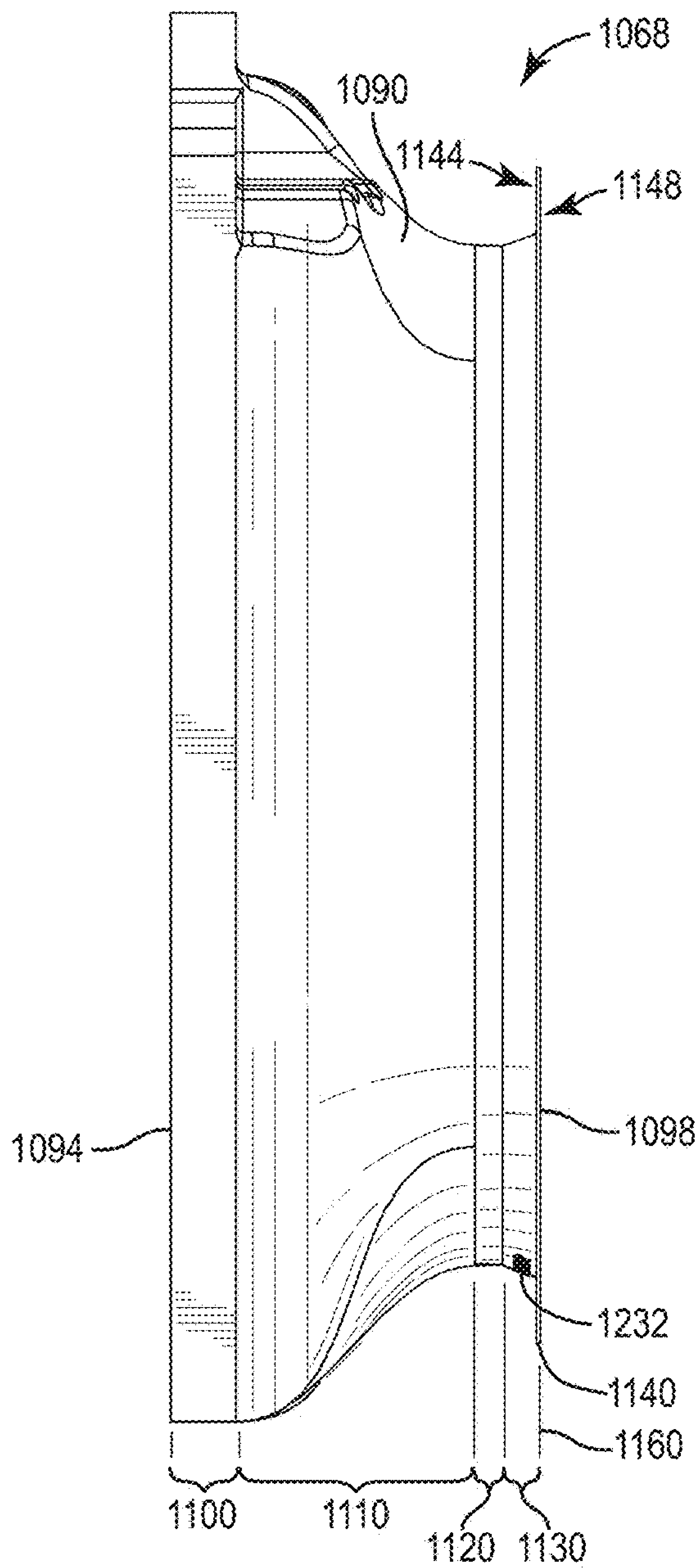

1068
1090
1144
1148
1094
1098
1232
1140
1160
1100
1110
1120
1130

FIG. 19

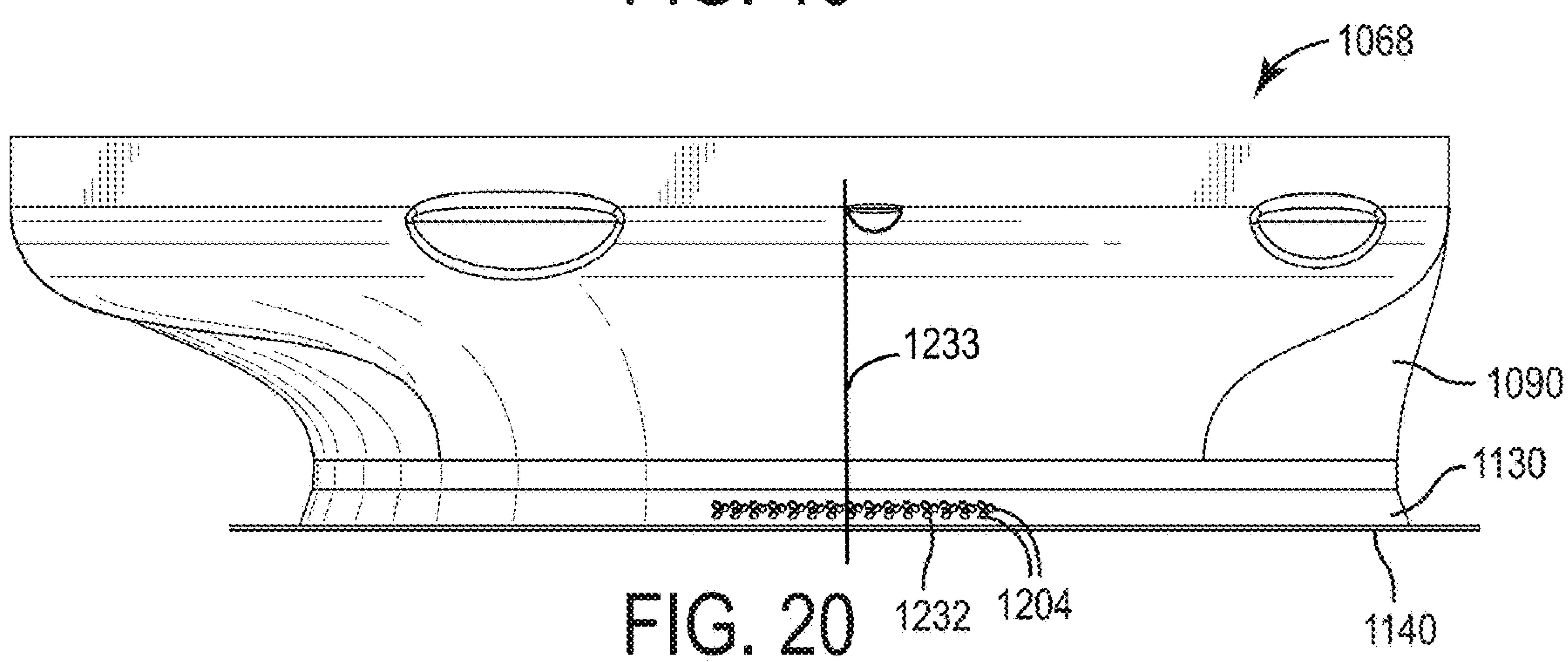

1068
1233
1090
1130
1232
1204
1140

FIG. 20

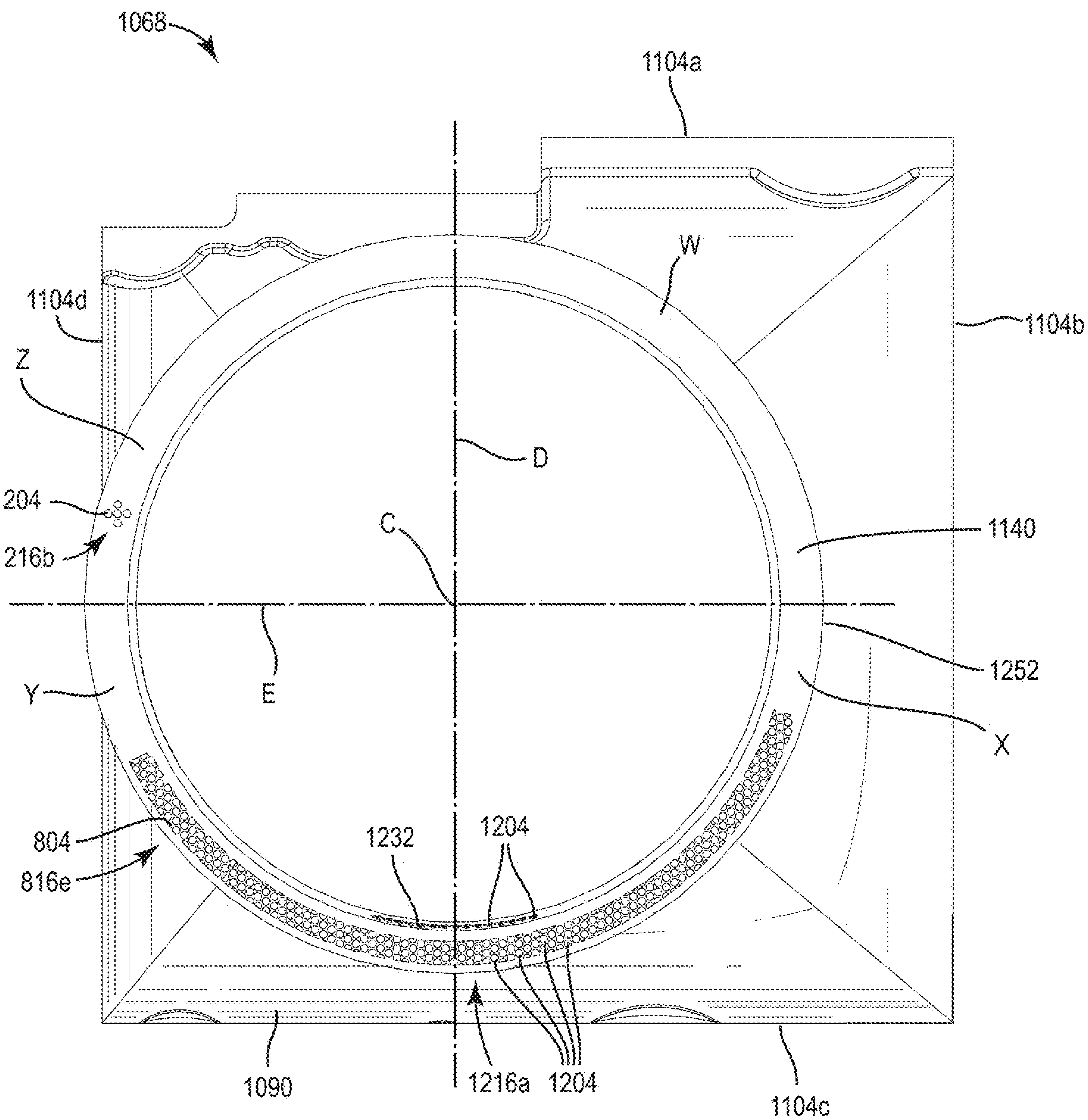

1068
1104a
W
1104d
1104b
Z
D
1204
C
1140
1216b
E
1252
Y
X
804
1232
1204
816e
1090
1216a
1204
1104c

FIG. 21

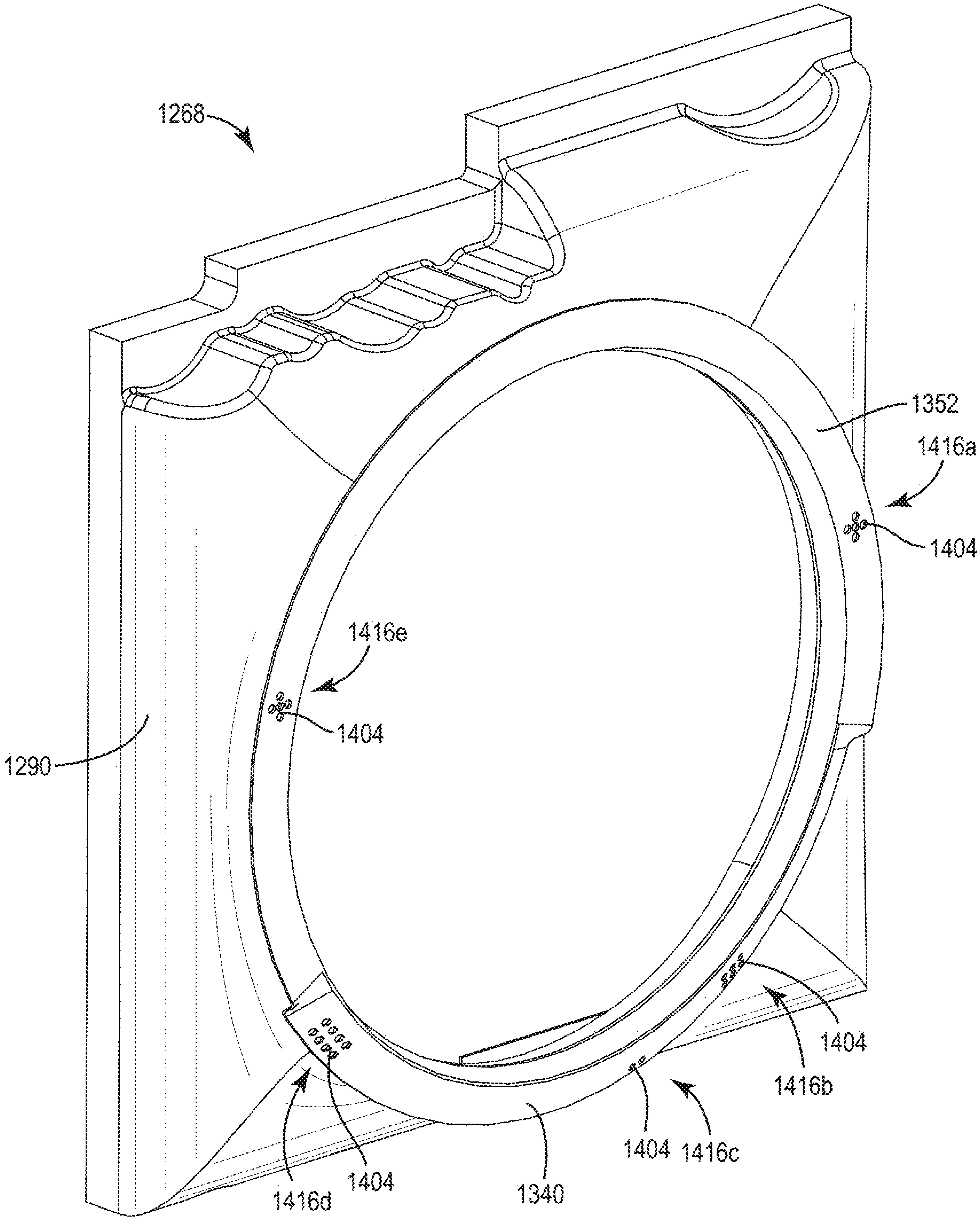
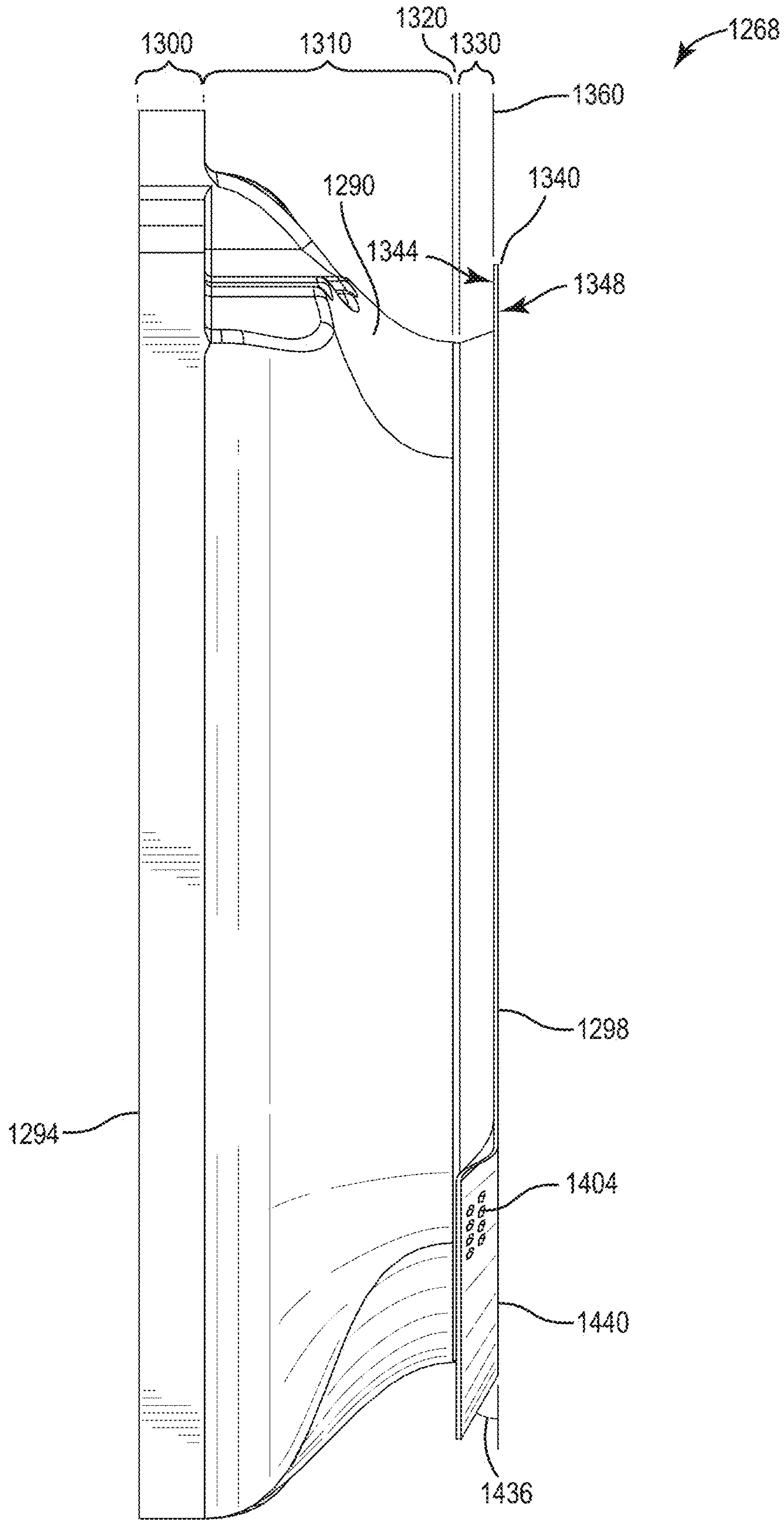

1268
1352
1416a
1404
1416e
1404
1290
1404
1416b
1404
1416c
1404
1416d
1404
1340

FIG. 22



1300
1310
1320
1330
1268
1360
1340
1290
1344
1348
1298
1294
1404
1440
1436

FIG. 23

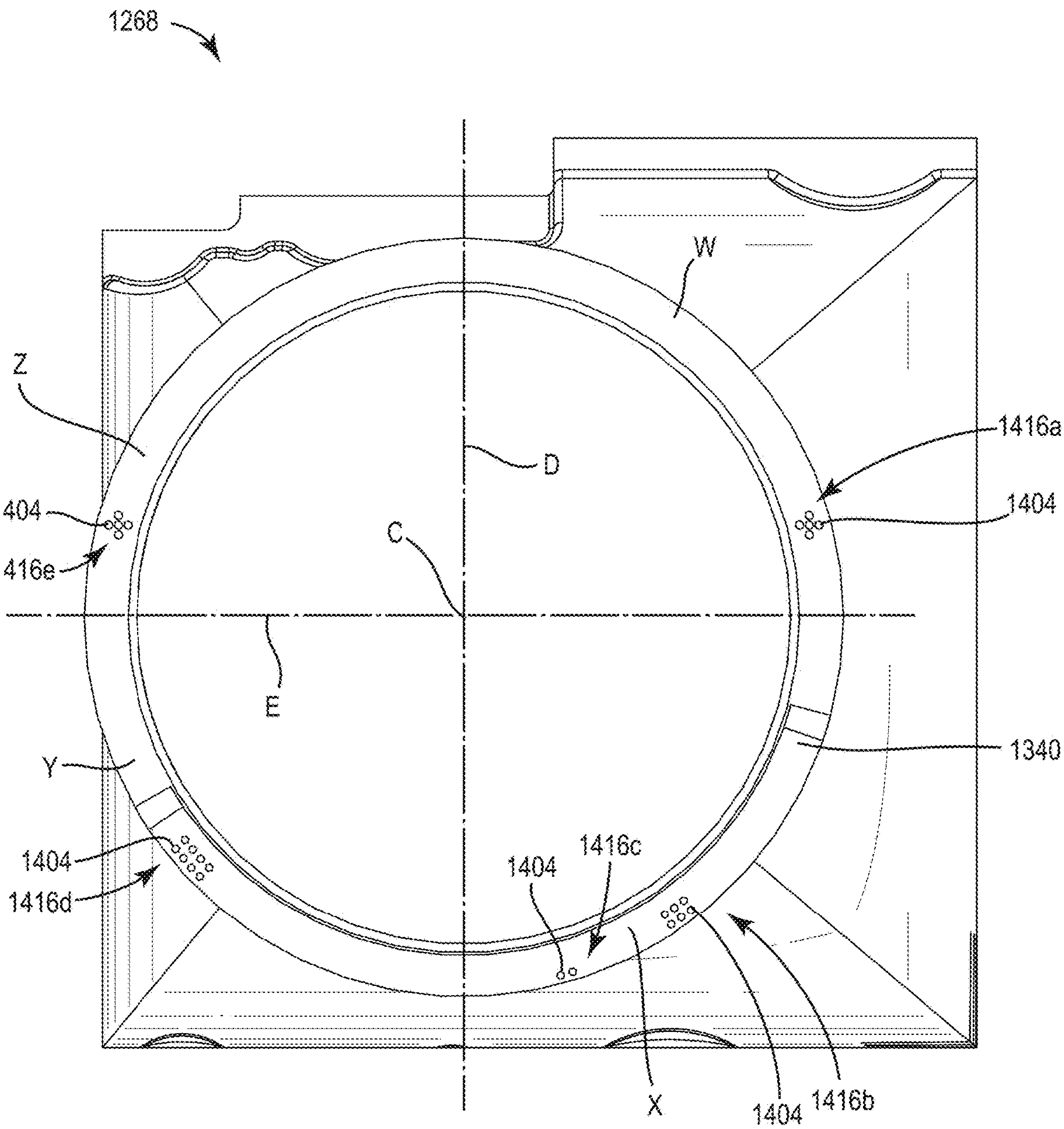

1268
W
Z
1416a
D
1404
1404
C
1416e
E
Y
1340
1404
1416c
1404
1416d
X
1404
1416b

FIG. 24

FAN SHROUD

BACKGROUND

The present disclosure relates to off-highway machines and specifically to a fan shroud for use with off-highway machines.

SUMMARY

One embodiment includes a shroud for a cooling fan that is positionable within the chassis of an off-highway machine. The shroud includes an inlet having a first external side, a second side, a third side, and a fourth side, and an outlet. An elliptical lip section is positioned at the outlet, and includes a first planar face and a second planar face facing away from the first planar face. The second planar face has a centroid. The shroud further includes a plane that is coincident with the second planar face. The plane includes a first axis parallel to the second and fourth sides of the inlet, and a second axis perpendicular to the first axis. Both the first axis and the second axis pass through the centroid. The first and second axes together divide the elliptical lip section into four quadrants, and a plurality of apertures extend through the elliptical lip section. At least one aperture of the plurality of apertures is positioned in each quadrant of the four quadrants of the elliptical lip section.

Another embodiment includes a shroud for a cooling fan that is being positionable within the chassis of an off-highway machine. The shroud includes an inlet, an outlet, an elliptical lip section positioned adjacent to the outlet, and a plurality of apertures extending through the elliptical lip section. Each aperture of the plurality of apertures is positioned greater than 10 degrees away from an adjacent aperture of the plurality of apertures.

Another embodiment includes a shroud for a cooling fan that is positionable within the chassis of an off-highway machine. The shroud includes an inlet, an outlet, and an elliptical lip section positioned adjacent to and extending radially outwardly from the outlet. The elliptical lip section defines a plane and includes a first planar face and a second planar face facing away from the first planar face. The second planar face has a centroid. The shroud further includes a plane that is coincident with the second planar face. The plane includes a first axis parallel to the second and fourth sides of the inlet and a second axis perpendicular to the first axis. Both the first axis and the second axis pass through the centroid. A plurality of apertures extend through the elliptical lip section and are configured to at least partially relieve a pressure gradient generated by a portion of the elliptical lip section.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of an off-highway machine.

FIG. **2** is a perspective view of an engine with a cooling package, a fan, and a shroud within a chassis of the off-highway machine of FIG. **1**.

FIG. **3** is a cross-sectional view through the portion of the chassis of FIG. **2** taken along **3-3**.

FIG. **4** is a schematic of airflow in one orientation through the cooling package, the fan, and the shroud of FIG. **2**.

FIG. **5** is a schematic of airflow in another orientation through the cooling package, the fan, and the shroud of FIG. **2**.

FIG. **6** is a side view of the shroud illustrated in FIG. **2**.

FIG. **7** is a rear view of a face of the shroud of FIG. **6**.

FIG. **8** is a computational fluid dynamics (CFD) simulation of air flow through the shroud of FIG. **7**.

FIG. **9** is a side view of a shroud according to one embodiment.

FIG. **10** is a rear view of the shroud of FIG. **9**.

FIG. **11** is a CFD simulation of air flow through the shroud of FIG. **9**.

FIG. **12** is a rear view of a shroud according to another embodiment.

FIG. **13** is a perspective view of a shroud according to another embodiment.

FIG. **14** is a side view of the shroud of FIG. **13**.

FIG. **15** is a rear view of the shroud of FIG. **13**.

FIG. **16** is a CFD simulation comparing airflow through the shroud of FIG. **6** to airflow through the shroud of FIG. **14**.

FIG. **17** is a side view of a shroud according to another embodiment.

FIG. **18** is a rear view of the shroud of FIG. **17**.

FIG. **19** is a side view of a shroud according to another embodiment.

FIG. **20** is another side view of the shroud of FIG. **19**.

FIG. **21** is a rear view of the shroud of FIG. **19**.

FIG. **22** is a perspective view of a shroud according to another embodiment.

FIG. **23** is a side view of the shroud of FIG. **22**.

FIG. **24** is a rear view of the shroud of FIG. **22**.

DETAILED DESCRIPTION

Before implementations of the disclosure are explained in detail, it is to be understood that the disclosure is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the accompanying drawings. The disclosure is capable of supporting other implementations and of being practiced or of being carried out in various ways. Moreover, the term 'substantially' is understood by those of ordinary skill to refer to reasonable ranges outside of the given value, for example, general tolerances or resolutions associated with manufacturing, assembly, and use of the described embodiments and components herein. Further, the term 'approximately' as used herein means plus or minus 5 degrees.

FIG. **1** illustrates an off-highway machine, such as an excavator **10**, having a chassis **14** and traction members (e.g., crawler mechanisms or tracks **18**) for supporting and propelling the chassis **14** and therefore the machine **10** along a surface. The traction members **18** are oriented parallel to a longitudinal axis A of the chassis **14**, which coincides with a forward direction of travel of the machine **10** during operation. In the illustrated embodiment, each crawler mechanism **18** includes a drive sprocket **42**, an undercarriage frame **46**, and a track **50**. The drive sprocket **42** is driven by a prime mover **54** and engages the track **50**. The track **50** is driven in an endless loop around the drive sprocket **42** and the undercarriage frame **46**. The machine **10** further includes an operator cab **22** and a tool or work attachment (e.g., a bucket **30**) supported on an end of an arm **32**.

Although the off-highway machine **10** is illustrated and described as an excavator, it is understood that the off-highway machine **10** may have a different form, such as a loader, a dozer, a motor grader, a scraper, or another type of construction, mining, agricultural, or utility machine. Also, although the work attachment is illustrated and described as a bucket, it is understood that the work attachment may have a different form, such as an auger, a breaker, a ripper, a grapple, or some other type of attachment for digging, breaking, handling, carrying, dumping or otherwise engaging dirt or other material. In addition, the work attachment may be detachable from the arm **32** to permit another type of work attachment to be coupled to the arm **32**.

As shown in FIGS. **2-3**, the chassis **14** houses an engine **62**. The engine **62** includes the prime mover **54**, a cooling package **60**, a fan **64**, and a shroud **68**, which are aligned along an axis B transverse to the longitudinal axis A (FIG. **1**). The cooling package **60** includes one or more heat exchangers or coolers **76**. Other underhood components (i.e., filters, pumps, conduits, reservoirs, sensors, batteries, valves, etc.) may also make up part of the overall engine **62**.

The schematics in FIGS. **4-5** illustrate that the fan **64** can operate in either a suction mode or a blower mode. In the suction mode, shown in FIG. **4**, airflow enters the cooling package **60** through the chassis **14** and then flows to the fan **64** and over portions of the engine **62**. In the blower mode, shown in FIG. **5**, airflow enters the fan **64** after passing over portions of the engine **62**, passes over and through the cooling package **60**, and exits via the chassis **14**.

In either flow configuration, the performance of the fan **64** is affected by virtue of its position between the cooling package **60** and the engine **62**. Specifically, the fan **64** is subjected to upstream and downstream loading. For example and with renewed reference to FIG. **3** (for example), when the fan **64** is mounted adjacent the engine **62** the air flow coming from the cooling package **60** and passing through the fan **64** is immediately subjected to blockage created by the engine block and other underhood components.

FIGS. **6-7** illustrate a conventional shroud **68**. The shroud **68** includes a body **90** having an inlet **94** and an outlet **98** opposite the inlet **94**. The body **90** defines a breathing section **100**, a convergence section **110**, a plateau section **120**, a divergence section **130**, and a lip section **140**. With respect to the orientation of FIG. **4**, the breathing section **100** collects air exiting the cooling package **60** and provides a steady region of weak pressure gradient to ease flow transition between the surfaces of the cooling package **60** and the convergence section **110**. The breathing section **110** is substantially rectangular and has a first side **104***a*, a second side **104***b*, a third side **104***c*, and a fourth side **104***d*. The length of the breathing section **100** (in the direction of axis B) may range from approximately 25 mm to approximately 100 mm depending on the overall shroud length, which is based on the engine type. The convergence section **110** guides accelerating air from the larger rectangular form of the breathing section **100** into a smaller circular cross-section within which the fan **64** is located. The convergence section **110** reduces flow separation and vortices by governing the acceleration of air to be slow enough to avoid turbulent transition of boundary layer air. The length of the convergence section **110** may range from approximately 150 mm to approximately 400 mm. The plateau section **120** transitions the shroud **68** between the convergence section **110** and the divergence section **130**, which contains and decelerates the airflow immediately after the fan **64** prior to release over the engine block of the engine **62**. The length of the plateau section **120** may range from approximately 5 mm to approximately 20 mm. The lip section **140** extends radially at the outlet **98** and presents opposing first and second faces **144**, **148** with a common perimeter or outer profile or boundary **152**. The lip section **140** may be used to mount a finger guard. In the embodiment illustrated in FIGS. **6-7**, the lip section **140** is circular, and has a radial distance of between 35 mm inches and 80 mm. The lip section **140** may have other suitable shapes and radial distances. For example, the lip section **140** may be elliptical with non-zero eccentricity or have any other suitable arcuate or curvilinear shape.

Further with respect to FIG. **6**, the outlet **98**, which can also be represented by the lip section **140**, is offset with respect to the inlet (i.e., the breathing section **100**). That is, the shroud **68** defines a centroid or geometric center C of the lip section **140** that is offset from a centroid or geometric center C' of the breathing section **100**. Moreover, a plane **160** is defined coincident with the second face **148**, within which are further defined a first axis D and a second axis E perpendicular to first axis D. The first axis D is perpendicular to the first and third sides **104***a*, **104***c* of the breathing section **100** and parallel to the second and fourth sides **104***b*, **104***d* of the breathing section **100**. The second axis E is parallel to the first and third sides **104***a*, **104***c* of the breathing section **100** and perpendicular to the second and fourth sides **104***b*, **104***d* of the breathing section **100**.

The lip section **140** of FIGS. **6** and **7**, by extending radially from the divergence section **130**, creates a high-pressure region that reduces overall airflow through the shroud, especially when coupled with airflow restrictions due to the proximity of the engine **62** (e.g., in the orientation of FIG. **4**). Effectively, and referring to FIG. **8**, the lip section **140** of FIGS. **6-7** facilitates pressure concentration regions **186** and low pressure regions **188**, as shown in a computational fluid dynamics (CFD) simulation of the shroud **68** during operation. Of note, the lip section **140** of FIGS. **6-7** is a non-fastening surface and is solid or continuous (i.e., without apertures or recesses formed wholly or partially in or through either the first or second faces **144**, **148**) about the centroid C.

FIGS. **9-10** illustrate a shroud **268** according to one embodiment. The shroud **268** of FIGS. **9-10** is similar to the shroud **68** of FIGS. **6-7** discussed above, and therefore like structure will be indicated with the same reference numerals plus 200. In particular, the shroud **268** of FIGS. **9-10** includes a breathing section **300**, a convergence section **310**, a plateau section **320**, a divergence section **330**, and a lip section **340**, as discussed above.

Further with respect to FIG. **10**, a plane **360** is defined coincident with the second face **348** and defines a first axis D and a second axis E, which are perpendicular to each other. The first axis D is perpendicular to the first and third sides **304***a*, **304***c* of the breathing section **300**, and parallel to the second and fourth sides **304***b*, **304***d* of the breathing section **300**. The second axis E is parallel to the first and third sides **304***a*, **304***c* of the breathing section **100** and perpendicular to the second and fourth sides **304***b*, **304***d* of the breathing section **100**. The lip section **340** further includes one or more apertures (i.e., openings) **404** extending therethrough. That is, the apertures **404** extend between the faces **344**, **348** of the lip section **340**. In the embodiment illustrated in FIGS. **9-10**, the apertures **404** are symmetric with respect to the axis D. Moreover, the axes D, E define four quadrants W, X, Y, Z of the lip section **340**, with one aperture **404** in each of the four quadrants W, X, Y, Z. In the embodiment illustrated in FIG. **10**, the lip section **340** is circular and therefore each quadrant W, X, Y, Z comprises a 90 degree arc length of the lip section **340**. In other or additional embodiments, the lip section may have other shapes and therefore each quadrant W, X, Y, Z may comprise other arc lengths. For example, the lip section **340** may be elliptical with non-zero eccentricity or have any other suitable arcuate or curvilinear shape. Moreover, because centroid C of the lip section **340** is offset with respect to the centroid C' of the breathing section **300** (in the view of FIG. **10**), quadrant Z (i.e., the quadrant defined in the top left portion of the lip section **340** in the view of FIG. **10**) is closest to the intersection of the first side **304***a* and the fourth side **304***d* of the inlet or breathing section **330**.

The apertures **404** may also be described as oriented according to degrees of a circle relative to the axis D about the lip section **340** (or the second face **348**). In particular, a first aperture **404***a* is oriented between approximately 70 degrees and approximately 90 degrees relative to the axis D (viewed closest to side **304***a* and clockwise therefrom in FIG. **10**), and more specifically, the first aperture **404***a* is oriented at approximately 75 degrees relative to the axis D. A second aperture **404***b* is oriented between approximately 130 degrees and approximately 175 degrees relative to the axis D, and more specifically, the second aperture **404***b* is oriented at approximately 140 degrees relative to the axis D. A third aperture **404***c* is oriented between approximately 185 degrees and approximately 235 degrees relative to the axis D, and more specifically, the third aperture **404***c* is oriented at approximately 220 degrees relative to the axis D. A fourth aperture **404***d* is oriented between approximately 270 degrees and approximately 315 degrees relative to the axis D, and more specifically, the fourth aperture **404***d* is oriented at approximately 285 degrees relative to the axis D.

The apertures **404** may also be described relative to one another. In the embodiment illustrated in FIGS. **9-10**, the apertures **404** are oriented at least 30 degrees away from one another. The first aperture **404***a* is oriented between approximately 30 degrees and approximately 90 degrees relative to the second aperture **404***b*, and more specifically, the first aperture **404***a* is oriented at approximately 70 degrees relative to the second aperture **404***b*. Accordingly, the arc length distance between the first and second apertures **404***a*, **404***b* measures substantially 495 mm, although in additional or alternative embodiments, the arc length may measure between substantially 210 mm and substantially 640 mm. The second aperture **404***b* is oriented between approximately 30 degrees and approximately 90 degrees relative to the third aperture **404***c*, and more specifically, the second aperture **404***b* is oriented at approximately 70 degrees relative to the third aperture **404***c*. Accordingly, the arc length distance between the second and third apertures **404***b*, **404***c* measures substantially 495 mm, although in additional or alternative embodiments, the arc length may measure between substantially 210 mm and substantially 640 mm. The third aperture **404***c* is oriented between approximately 30 degrees and approximately 90 degrees relative to the fourth aperture **404***d*, and more specifically, the third aperture **404***c* is oriented at approximately 70 degrees relative to the fourth aperture **404***d*. Accordingly, the arc length distance between the third and fourth apertures **404***c*, **404***d* measures substantially 495 mm, although in additional or alternative embodiments, the arc length may measure between substantially 210 mm and substantially 640 mm. The fourth aperture **404***d* is oriented at between approximately 140 degrees and approximately 180 degrees relative to the first aperture **404***a*, and mores specifically, the fourth aperture **404***d* is oriented at approximately 150 degrees relative to the first aperture **404***a*. Accordingly, the arc length distance between the first and fourth apertures **404***a*, **404***d* measures substantially 1060 mm, although in additional or alternative embodiments, the arc length may measure between substantially 990 mm and substantially 1280 mm.

The embodiment of FIG. **10** includes apertures **404** that are substantially circular, although as discussed in greater detail herein, the apertures **404** may be any suitable shape. Additionally, the embodiment of FIG. **10** includes apertures **404** that are substantially the same size, although in other embodiments the aperture may have any suitable size. In the illustrated embodiment, the apertures measure substantially 25.0 mm, although in other or additional embodiments, the apertures may measure between substantially 20.0 mm and substantially 30.0 mm.

In one embodiment, the apertures **404** of the shroud **268** of FIGS. **9-10** were placed in approximate alignment with the pressure concentration regions **186** previously described with respect to FIG. **8**. The CFD results illustrated in FIG. **11** show the pressure distribution during operation at the same downstream planar position of shroud **268** as was illustrated in FIG. **8** with respect to shroud **68** (i.e., near planes **160** and **360**). As a result of the presence of the apertures **404**, the size and overall intensity of the pressure concentration regions **386** are significantly less intense. In addition, the low-pressure regions **388** in front of the fan **64** are also reduced in intensity. Overall, the pressure distribution in front of the fan **64** is much more homogeneous as indicated by the reduced regions **386**, **388**. Additionally, the reduced pressure regions **386** represent that airflow is guided more efficiently through the shroud **268** and cooling package **60**, which results in more effective cooling of the engine **62**.

FIG. **12** shows a shroud **468** according to another embodiment. The shroud **468** of FIG. **17** is similar to the shroud **268** of FIGS. **14-15** discussed herein, and therefore like structure will be indicated with the same reference numerals plus 200. The shroud **468** includes a lip section **540** having a plurality of apertures **604'** that are symmetric relative to the axis D and a plurality of apertures **604"** that are not symmetric with respect to the axis D. Moreover, the axes D, E define four quadrants W, X, Y, Z of the lip section **540**, with a plurality of apertures **604** in each of the four quadrants W, X, Y, Z.

The apertures **604** may also be described as oriented according to degrees of a circle relative to the axis D. In particular, a first aperture **604***a* is oriented between approximately 10 degrees and approximately 20 degrees relative to the axis D (viewed closest to side **504***a* and clockwise therefrom), and more specifically, the first aperture **604***a* is oriented at approximately 15 degrees relative to the axis D. A second aperture **604***b* is oriented between approximately 40 degrees and approximately 50 degrees relative to the axis D, and more specifically, the second aperture **604***b* is oriented at approximately 45 degrees relative to the axis D. A third aperture **604***c* is oriented between approximately 60 degrees and approximately 70 degrees relative to the axis D, and more specifically, the third aperture **604***c* is oriented at approximately 75 degrees relative to the axis D. A fourth aperture **604***d* is oriented between approximately 100 degrees and approximately 110 degrees relative to the axis D, and more specifically, the fourth aperture **604***d* is oriented between approximately 105 degrees relative to the axis D. A fifth aperture **604***e* is oriented between approximately 130 degrees and approximately 140 degrees relative to the axis D, and more specifically, the fifth aperture **604***e* is oriented at approximately 135 degrees relative to the axis D. A sixth aperture **604***f* is oriented between approximately 160 degrees and approximately 170 degrees relative to the axis D, and more specifically, the sixth aperture **604***f* is oriented at approximately 165 degree relative to the axis D. A seventh aperture **604***g* is oriented between approximately 170 degrees and approximately 180 degrees relative to the axis D, and more specifically, the seventh aperture **604***g* is oriented at approximately 175 degrees relative to the axis D. An eighth aperture **604***h* is oriented between approximately 180 degrees and approximately 190 degrees relative to the axis D, and more specifically, the eighth aperture **604**h is oriented at approximately 185 degrees relative to the axis D. A ninth aperture **604**i is oriented between approximately 190 degrees and approximately 200 degrees relative to the axis D, and more specifically, the ninth aperture **604**i is oriented at approximately 195 degrees relative to the axis D. A tenth aperture **604**j is oriented between approximately 200 degrees and approximately 210 degrees relative to the axis D, and more specifically, the tenth aperture **604**j is oriented at approximately 205 degrees relative to the axis D. An eleventh aperture **604**k is oriented between approximately 210 degrees and approximately 220 degrees relative to the axis D, and more specifically, the eleventh aperture **604**k is oriented at approximately 215 degrees relative to the axis D. A twelfth aperture **604**l is oriented between approximately 220 degrees and approximately 230 degrees relative to the axis D, and more specifically, the twelfth aperture **604**l is oriented at approximately 225 degrees relative to the axis D. A thirteenth aperture **604**m is oriented between approximately 250 degrees and approximately 260 degrees relative to the axis D, and more specifically, the thirteenth aperture **604**m is oriented at approximately 255 degrees relative to the axis D. A fourteenth aperture **604**n is oriented between approximately 280 degrees and approximately 290 degrees relative to the axis D, and more specifically, the fourteenth aperture **604**n is oriented at approximately 285 degree relative to the axis D. A fifteenth aperture **604**o is oriented between approximately 310 degrees and approximately 320 degrees relative to the axis D, and more specifically, the fifteenth aperture **604**o is oriented at approximately 315 degrees relative to the axis D. A sixteenth aperture **404**p is oriented between approximately 340 degrees and approximately 350 degrees relative to the axis D, and more specifically, the sixteenth aperture **604**p is oriented at approximately 345 degrees relative to the axis D.

The apertures **604** may also be described relative to one another. In the embodiment illustrated in FIG. **12**, each of the apertures **604'** is oriented at least 30 degrees away from an adjacent aperture **604'** and each of the apertures **604"** are oriented at least 10 degrees away from an adjacent aperture **604"**. Accordingly, the arc length distance between the adjacent apertures **604'** measures substantially 185 mm, although in additional or alternative embodiments, the arc length may measure between substantially 125 mm and substantially 250 mm. Moreover, the arc length distance between the adjacent apertures **604"** measures substantially 60 mm, although in additional or alternative embodiments, the arc length may measure between substantially 30 mm and substantially 95 mm. Further with respect to FIG. **12**, the first aperture **604**a is oriented between approximately 20 degrees and approximately 40 degrees relative to the second aperture **604**b, and more specifically, the first aperture **604**a is oriented at approximately 30 degrees relative to the second aperture **604**b. The second aperture **604**b is oriented between approximately 20 degrees and approximately 40 degrees relative to the third aperture **604**c, and more specifically, the second aperture **604**b is oriented at approximately 30 degrees relative to the third aperture **604**c. The third aperture **404**c is oriented between approximately 20 degrees and approximately 40 degrees relative to the fourth aperture **604**d, and more specifically, the third aperture **404**c is oriented at approximately 30 degrees relative to the fourth aperture **604**d. The fourth aperture **604**d is oriented between approximately 20 degrees and approximately 40 degrees relative to the fifth aperture **604**e, and more specifically, the fourth aperture **604**d is oriented at approximately 30 degrees relative to the fifth aperture **604**e. The fifth aperture **604**e is oriented between approximately 20 degrees and approximately 40 degrees relative to the sixth aperture **604**f, and more specifically, the fifth aperture **604**e is oriented at approximately 30 degrees relative to the sixth aperture **604**f. The sixth aperture **604**f is oriented between approximately 5 degrees and approximately 15 degrees relative to the seventh aperture **604**g, and more specifically, the sixth aperture **604**f is oriented at approximately 10 degrees relative to the seventh aperture **604**g. The seventh aperture **604**g is oriented between approximately 5 degrees and approximately 15 degrees relative to the eighth aperture **604**h, and more specifically, the seventh aperture **604**g is oriented at approximately 10 degrees relative to the eighth aperture **604**h. The eighth aperture **604**h is oriented between approximately 5 degrees and approximately 15 degrees relative to the ninth aperture **604**i, and more specifically, the eighth aperture **604**h is oriented at approximately 10 degrees relative to the ninth aperture **604**i. The ninth aperture **604**i is oriented between approximately 5 degrees and approximately 15 degrees relative to the tenth aperture **604**j, and more specifically, the ninth aperture **604**i is oriented at approximately 10 degrees relative to the tenth aperture **604**j. The tenth aperture **604**j is oriented between approximately 5 degrees and approximately 15 degrees relative to the eleventh aperture **604**k, and more specifically, the tenth aperture **604**j is oriented at approximately 10 degrees relative to the eleventh aperture **604**k. The eleventh aperture **604**k is oriented between approximately 5 degrees and approximately 15 degrees relative to the twelfth aperture **604**l, and more specifically, the eleventh aperture **604**k is oriented at approximately 10 degrees relative to the twelfth aperture **604**l. The twelfth aperture **604**l is oriented between approximately 20 degrees and approximately 40 degrees relative to the thirteenth aperture **604**m, and more specifically, the twelfth aperture **604**l is oriented at approximately 30 degrees relative to the thirteenth aperture **604**m. The thirteenth aperture **604**m is oriented between approximately 20 degrees and approximately 40 degrees relative to the fourteenth aperture **604**n, the thirteenth aperture **604**m is oriented at approximately 30 degrees relative to the fourteenth aperture **604**n. The fourteenth aperture **604**n is oriented between approximately 20 degrees and approximately 40 degrees relative to the fifteenth aperture **604**o, and more specifically, the fourteenth aperture **604**n is oriented at approximately 30 degrees relative to the fifteenth aperture **604**o. The fifteenth aperture **604**o is oriented between approximately 20 degrees and approximately 40 degrees relative to the sixteenth aperture **604**p, and more specifically, the fifteenth aperture **604**o is oriented at approximately 30 degrees relative to the sixteenth aperture **604**p. The sixteenth aperture **604**p is oriented between approximately 20 degrees and approximately 40 degrees relative to the first aperture **604**a, and more specifically, the sixteenth aperture **604**p is oriented at approximately 30 degrees relative to the first aperture **604**a.

The embodiment of FIG. **12** includes apertures **604** that are substantially circular, although as discussed in greater detail herein, the apertures **604** may be any suitable shape. Additionally, the embodiment of FIG. **12** includes apertures **604** that are substantially the same size, although in other embodiments the aperture may have any suitable size. In the illustrated embodiment, the apertures measure substantially 25.0 mm, although in other or additional embodiments, the apertures may measure between substantially 20.0 mm and substantially 30.0 mm.

FIGS. **13-15**, illustrate a shroud **668** according to another embodiment. The shroud **668** of FIGS. **13-15** is similar to the shroud **268** of FIGS. **9-10** discussed above, and therefore like structure will be indicated with the same reference numerals plus 400, to include the existence of axis D and axis E. In the embodiment illustrated in FIGS. **13-15**, the apertures **804** are arranged in clusters **816**. In particular, the lip section **740** has a first cluster **816***a* of five apertures **804** in quadrant W, a second cluster **816***b* including six apertures **804** in quadrant X, a third cluster **816***c* including two apertures **804** in quadrant X, a fifth cluster **816***d* including three apertures **804** in quadrant Y, and a fifth cluster **816***e* including five apertures **804** in quadrant Z. The first and fifth clusters **816***a*, **816***e* are symmetric with respect to the axis D, and the second, third, and fourth clusters **816***b*, **816***c*, **816***d* are asymmetric with respect to the axis D.

The apertures **804** may also be described as oriented according to degrees of a circle relative to the axis D. In particular, the first cluster **816***a* is centered between approximately 70 degrees and approximately 90 degrees relative to the axis D (viewed closest to side **704***a* and clockwise therefrom), and more specifically, the first cluster **816***a* is centered at approximately 75 degrees relative to the axis D. The second cluster **816***b* is centered between approximately 130 and approximately 175 degrees relative to the axis D, and more specifically, the second cluster **816***b* is centered at approximately 140 degrees relative to the axis D. The third cluster **816***c* is centered between approximately 160 degrees and approximately 190 degrees relative to the axis D, and more specifically, the third cluster **816***c* is centered at approximately 165 degrees relative to the D axis. The fourth cluster **816***d* is centered between approximately 185 degrees and approximately 235 degrees relative to the axis D, and more specifically, the fourth cluster **816***d* is centered at approximately 225 degrees relative to the axis D. The fifth cluster **816***e* is centered between approximately 270 degrees and approximately 315 degrees relative to the axis D, and more specifically, and the fifth cluster **816***e* is centered at approximately 285 degrees relative to the axis D.

The apertures **804** may also be described relative to one another. In the embodiment illustrated in FIGS. **13-15**, the centers of the clusters **816** are oriented at least 10 degrees away from one another. That is, a center of the first cluster **816***a* is oriented between approximately 40 degrees and approximately 70 degrees relative to a center of the second cluster **816***b*, and more specifically, the center of the first cluster **816***a* is oriented at approximately 65 degrees relative to the center of the second cluster **816***b*. Accordingly, the arc length distance between the centers of the first and second clusters **816***a*, **816***b* measures substantially 460 mm, although in additional or alternative embodiments, the arc length may measure between substantially 280 mm and substantially 500 mm. The center of the second cluster **816***b* oriented between approximately 5 degrees and approximately 35 degrees relative to a center of the third cluster **816***c*, and more specifically, the center of the second cluster **816***b* is oriented at approximately 15 degrees relative to the center of the third cluster **816***c*. Accordingly, the arc length distance between the centers of the second and third clusters **816***b*, **816***c* measures substantially 105 mm, although in additional or alternative embodiments, the arc length may measure between substantially 35 mm and substantially 250 mm. The center of the third cluster **816***c* is oriented between approximately 50 degrees and approximately 80 degrees relative to a center of the fourth cluster **816***d*, and more specifically, the center of the third cluster **816***c* is oriented at approximately 60 degrees relative to the center of the fourth cluster **816***d*. Accordingly, the arc length distance between the centers of the third and fourth clusters **816***c*, **816***d* measures substantially 425 mm, although in additional or alternative embodiments, the arc length may measure between substantially 350 mm and substantially 570 mm. The center of the fourth cluster **816***d* is oriented between approximately 40 degrees and approximately 70 degrees relative to a center of the fifth cluster **816***e*, and more specifically, the center of the fourth cluster **816***d* is oriented at approximately 60 degrees relative to the center of the fifth cluster **816***e*. Accordingly, the arc length distance between the centers of the fourth and fifth clusters **816***d*, **816***e* measures substantially 460 mm although in additional or alternative embodiments, the arc length may measure between substantially 280 mm and substantially 500 mm. The center of the fifth cluster **816***e* is oriented between approximately 140 degrees and approximately 180 degrees relative to the center of the first cluster **816***a*, and more specifically, the center of the fifth cluster **816***e* is oriented at approximately 150 degrees relative to the center of the first cluster **816***a*. Accordingly, the arc length distance between the centers first and fifth clusters **816***a*, **816***e* measures substantially 1065 mm, although in additional or alternative embodiments, the arc length may measure between substantially 990 mm and substantially 1280 mm.

Moreover, the embodiment of FIGS. **13-15** includes clusters **816** that are arranged in a "+" shaped configuration (i.e., the first and fifth clusters **816***a*, **816***e*), a line configuration (i.e., the fourth and fifth clusters **816***d*, **816***e*), and a double-line configuration (i.e., the third cluster **816***c*). The apertures **804** may have other shapes, sizes, and cluster configurations. In the illustrated embodiment, the apertures of clusters **816***a*-**816***e* measure substantially 9.0 mm. Moreover, the width and height (measured between the centers of the apertures) of clusters **816***a*, **816***e* measure substantially 11.0 mm. Alternatively, the apertures of the clusters **816***b*-**816***d* may be hexagonal. In particular, the hexagonal apertures may be 120-degree equal sided hexagons having sides with lengths measuring substantially 4.5 mm. Hexagonal apertures are spaced apart from one another by substantially 4.5 mm gaps. The apertures of clusters **816***a*-**816***e* are spaced apart from an inside edge of the lip section **740** by substantially 6.0 mm.

Like the apertures **404** of the shroud **268**, the apertures **804** of the shroud **668** reduce the pressure concentration regions created by the lip section **740** and increase airflow. As shown in Table 1, below, the shroud **668** illustrated in FIGS. **13-15** having the configuration of apertures **804** and clusters **816** discussed above provides an increase in airflow in comparison to the shroud **68** of FIGS. **6-7**, which has no apertures.

TABLE 1

Shroud Design	Airflow through shroud [m^3/min]
Shroud 68 of FIGS. 6-7	290.134
Shroud 668 of FIGS. 13-15	298.913

The airflow of Table 1 was generated by a simulation that defined a fan speed of 1893 RPM, the maximum rated speed during normal operation.

As shown in FIG. **16**, the pressure and velocity fields near the shroud outlet **98**, **698** were also analyzed for both the shroud **68** of the prior art shown in FIGS. **6-7** and the shroud **668** shown in FIGS. **13-15**. In comparing the CFD results in FIG. **16**, the high-speed vortices **182**, **782** in the upper region and the low-speed vortices **182**, **782** in the lower region of the shroud **68**, **668** are suppressed in the shroud **668** of FIGS. **13-15** as compared to the shroud **68** of FIGS. **6-7**.

FIGS. **17-18** show a shroud **868** according to another embodiment. The shroud **868** of FIGS. **17-18** is similar to the shroud **268** of FIGS. **9-10** discussed above, and therefore like structure will be indicated with the same reference numerals plus 600. The lip section **940** has a first cluster **1016***a* of five apertures **1004**, a second cluster **1016***b* including a plurality of apertures **1004**, and a third cluster **1016***c* including five apertures **1004**. The first cluster **1016***a* is positioned in quadrant W and the third cluster **1016***c* is positioned in quadrant Z. The second cluster **1016***b* is positioned in and extends between quadrants X and Z. As shown in FIG. **18**, the first and third clusters **1016***a*, **1016***c* are symmetric with respect to the axis D.

The apertures **1004** may also be described as oriented according to degrees of a circle relative to the axis D. In particular, the first cluster **1016***a* is centered between approximately 70 degrees and approximately 90 degrees relative to the axis D (viewed closest to side **904***a* and clockwise therefrom), and more specifically, the first cluster **1016***a* is centered at approximately 75 degrees relative to the axis D. The second cluster **1016***b* is centered between approximately 170 degrees and approximately 190 degrees relative to the D axis, and more specifically, the second cluster **1016***b* extends between approximately 130 and approximately 235 degrees relative to the axis D. The third cluster **1016***c* is centered between approximately 270 degrees and approximately 315 degrees relative to the axis D, and more specifically, the third cluster **1016***c* is centered at approximately 285 degrees relative to the axis D.

The apertures **1004** may also be described relative to one another. In the embodiment illustrated in FIGS. **17-18**, the clusters **1016** are oriented at least 30 degrees away from one another. That is, a center of the first cluster **1016***a* is oriented between approximately 90 degrees and approximately 110 degrees relative to a center of the second cluster **1016***b*, and more specifically, the center of the first cluster **1016***a* is oriented at approximately 105 degrees relative to the center of the second cluster **1016***b*. Moreover, a center of the first cluster **1016***a* is oriented at approximately 52 degrees relative to an edge of the second cluster **1016***b*. Accordingly, the arc length distance between the center of the first cluster **1016***a* and an edge of the second cluster **1016***b* measures substantially 370 mm, although in additional or alternative embodiments, the arc length may measure between substantially 295 mm and substantially 440 mm. The center of the second cluster **1016***b* oriented between approximately 90 degrees and approximately 110 degrees relative to a center of the third cluster **1016***c*, and more specifically, the center of the second cluster **1016***b* is oriented at approximately 105 degrees relative to the center of the third cluster **1016***c*. Moreover, an edge of the second cluster **1016***b* is oriented at approximately 52 degrees relative to the center of the third cluster **1016***c*. Accordingly, the arc length distance between the edge of the second cluster **1016***b* and the center of the third cluster **1016***c* measures substantially 370 mm, although in additional or alternative embodiments, the arc length may measure between substantially 295 mm and substantially 440 mm. The center of the third cluster **1016***c* is oriented between approximately 140 degrees and approximately 180 degrees relative to the center of the first cluster **1016***a*, and more specifically, the center of the third cluster **1016***c* is oriented at approximately 150 degrees relative to the center of the first cluster **1016***a*. Accordingly, the arc length distance between the centers first and third clusters **1016***a*, **1016***c* measures substantially 1065 mm, although in additional or alternative embodiments, the arc length may measure between substantially 990 mm and substantially 1280 mm.

The embodiment of FIGS. **17-18** includes apertures **1004** that are substantially circular. Moreover, the embodiment of FIGS. **17-18** includes clusters **1016** that are arranged in a "+" shaped configuration (i.e., first and third clusters **1016***a*, **1016***c*) and that are arranged in a staggered configuration (i.e., second cluster **1016***b*). The apertures **1004** may have other shapes, sizes, and cluster configurations. In the illustrated embodiment, the apertures of clusters **1016***a*, **1016***c* measure substantially 9.0 mm. Moreover, the width and height (measured between the centers of the apertures) of clusters **1016***a*, **1016***c* measure substantially 11.0 mm. The apertures of cluster **1016***b* measure substantially 9.0 mm. Further, a distance between apertures in the same row (measured center-to-center) is substantially 20.0 mm. Moreover, the apertures are positioned relative to one another at 60-degree angles.

FIGS. **19-21** show a shroud **1068** according to another embodiment. The shroud **1068** of FIGS. **19-21** is similar to the shroud **268** of FIGS. **9-10** discussed above, and therefore like structure will be indicated with the same reference numerals plus 800. In the embodiment illustrated in FIGS. **24-26**, the lip section **1140** has a first cluster **1216** including a plurality of apertures **1204** and a second cluster **1016***b* of five apertures **1204**. The first cluster **1216***a* is positioned in and extends between quadrants X and Y and the second cluster **1216***b* is positioned in quadrant Z. In the embodiment of FIGS. **19-21**, the divergence section **1130** has apertures **1204** that are arranged in a third cluster **1232**, as well.

Further, the apertures **1204** may also be described as oriented according to degrees of a circle relative to the axis D. In particular, the first cluster **1216***a* is centered between approximately 170 degrees and approximately 190 degrees relative to the D axis (viewed closest to side **1104***a* and clockwise therefrom), and more specifically, the first cluster **1216***a* extends between approximately 110 and approximately 245 degrees relative to the axis D. The second cluster **1216***b* is centered between approximately 270 degrees and approximately 315 degrees relative to the axis D, and more specifically, the second cluster **1216***b* is centered at approximately 285 degrees relative to the axis D. The divergence section **1130** is substantially concentric with the lip section **1140**. Accordingly, the third cluster **1232** is centered between approximately 170 degrees and approximately 190 degrees relative to the D axis, and more specifically, the third cluster **1232** extends between approximately 165 degrees and approximately 195 degrees relative to the axis D. The apertures of the third cluster **1232** are hexagons. The hexagons are spaced (center-to-center) substantially 2 mm apart. Also, the hexagonal apertures are positioned in groups of the three and patterned at a two degree offset around a centerline **1233** of the shroud. Moreover, the hexagonal apertures have two sides that measure substantially 3.5 mm and the height between these two sides measures substantially 5.0 mm. That is, the apertures extend substantially 95 mm in one direction from the centerline **1233** and substantially 100 mm in the opposite direction from the centerline **1233**. Accordingly, the apertures of the third cluster **1232** extend substantially 195 mm along the arc length of the divergence section **1130**. The hexagonal apertures of the third cluster **1232** are additionally positioned substantially 7.0 mm from an edge of divergence section **1130**.

The apertures **1204** may also be described relative to one another. That is, a center of the first cluster **1216***a* is oriented between approximately 90 degrees and approximately 110 degrees relative to a center of the second cluster **1216***b*, and more specifically, the center of the first cluster **1216***a* is oriented at approximately 105 degrees relative to the center of the second cluster **1216***b*. Moreover, an edge of the first cluster **1216***a* is oriented at approximately 40 degrees relative to the center of the second cluster **1216***b*. Accordingly, the arc length distance between the edge of the first cluster **1216***a* and the center of the second cluster **1216***b* measures substantially 280 mm, although in additional or alternative embodiments, the arc length may measure between substantially 210 mm and substantially 425 mm. The center of the second cluster **1216***b* is oriented between approximately 240 degrees and approximately 270 degrees relative to the center of the first cluster **1216***a*, and more specifically, the center of the second cluster **1216***b* is oriented at approximately 255 degrees relative to the center of the first cluster **1216***a*. Moreover, a center of the second cluster **1216***b* is oriented at approximately 185 degrees relative to an edge of the first cluster **1216***a*. Accordingly, the arc length distance between the center of the second cluster **1216***b* and an edge of the first cluster **1216***a* measures substantially 1310 mm, although in additional or alternative embodiments, the arc length may measure between substantially 1240 mm and substantially 1385 mm.

The embodiment of FIGS. **19-21** includes apertures **1204** that are substantially circular. Moreover, the embodiment of FIGS. **19-21** includes clusters **1216** that are arranged in a "+" shaped configuration (i.e., second cluster **1216***b*) and that are arranged in a staggered configuration (i.e., first and third clusters **1216***a*, **1232**). The apertures **1204** may have other shapes, sizes, and cluster configurations. In the illustrated embodiment, the apertures of cluster **1216***b* measures substantially 9.0 mm. Moreover, the width and height (measured between the centers of the apertures) of cluster **1216***b* measures substantially 11.0 mm. The apertures of cluster **1216***a* measure substantially 9.0 mm and the distance between adjacent apertures (measured center-to-center) is substantially 11.0 mm. The apertures are centered on the lip section **1140** and are positioned at least 10.0 mm away from both inside and outside edges of the lip section **1140**.

FIGS. **22-24** show a shroud **1268** according to another embodiment. The shroud **1268** of FIGS. **22-24** is similar to the shroud **268** of FIGS. **9-10** discussed above, and therefore like structure will be indicated with the same reference numerals plus 1000. Further, the shroud **1268** has the same aperture **1404** and cluster **1016** configuration as the shroud **668** of FIGS. **13-15** except that the fourth cluster **1416***d* has eight apertures **1404** rather than three apertures, and therefore has a double-line configuration rather than a line configuration. That is, the arc length distance between the centers first and fifth clusters **1416***a*, **1416***e* measures substantially 1065 mm, although in additional or alternative embodiments, the arc length may measure between substantially 990 mm and substantially 1280 mm. Moreover, an edge of the second cluster **1416***b* is spaced substantially 225 mm from the first axis D, an edge of the third cluster **1416***c* is spaced substantially 105 mm from the first axis D, and an edge of the fourth cluster **1416***d* is spaced substantially 280 mm from the first axis D. The second and third clusters **1416***b*, **1416***c* are positioned on one side of the first axis D and the fourth cluster **1416***d* is positioned on an opposite side the first axis D. Additionally, in the embodiment of FIGS. **22-24**, the lip section **1340** has an angled portion that is oriented at an angle **1436** with respect to the plane **1360** that is coincident with the face **1348** of the lip section **1340**. The angled portion facilitates the flow of air towards a bottom of the engine. In the illustrated embodiment, second, third, and fourth clusters **1416***b*, **1416***c*, **1416***d* are positioned on the angled portion of the lip section **1340**. In the illustrated embodiment, the angle **1436** is approximately 30 degrees, although in other or additional embodiments the angle **1436** may range from between approximately 15 degrees to approximately 30 degrees.

Moreover, the embodiment of FIGS. **22-24** includes clusters **1416** that are arranged in a "+" shaped configuration (i.e., the first and fifth clusters **1416***a*, **1416***e*), a line configuration (i.e., the third cluster **1416***c*), and a double-line configuration (i.e., the second and fifth cluster **1416***b*, **1416***d*). The apertures **1404** may have other shapes, sizes, and cluster configurations.

The shrouds **268**, **468**, **668**, **868**, **1068**, **1268** of FIGS. **9-10**, **12-15**, and **17-24** are discussed in reference to the suction mode of operation shown in FIG. **4**. Moreover, the shrouds **268**, **468**, **668**, **868**, **1068**, **1268** of FIGS. **9-10**, **12-15**, and **17-24** create more favorable pressure gradients to further increase airflow across heat exchangers of the cooling package **60**, resulting in greater heat transfer from cooling circuit fluids and hot under-hood components to the air. Accordingly, the preferred aperture and cluster locations discussed above are dependent on the downstream obstruction location and the escape path of the airflow from the shroud exit. In other words, the main purpose of the additional apertures and clusters discussed herein is to facilitate the movement of flow through and from the respective shroud. As discussed above, the apertures may be circular or hexagonal, although in other embodiments the apertures may be rectangular or triangular.

Various features of the disclosure are set forth in the following claims.

What is claimed is:

1. A shroud for a cooling fan, the fan positionable within the chassis of an off-highway machine, the shroud comprising:

an inlet having a first side, a second side, a third side, and a fourth side;

an outlet; and

an elliptical lip section positioned at the outlet, the elliptical lip section including a first planar face and a second planar face facing away from the first planar face, the second planar face having a centroid,

wherein a plane coincident with the second planar face includes a first axis parallel to the second and fourth sides of the inlet and a second axis perpendicular to the first axis, both the first axis and the second axis passing through the centroid, wherein the first and second axes together divide the elliptical lip section into four quadrants,

wherein a plurality of apertures extend through the elliptical lip section, at least one aperture of the plurality of apertures positioned in each quadrant of the four quadrants of the elliptical lip section, and

wherein the plurality of apertures is arranged in aperture clusters.

2. The shroud of claim **1**, wherein the apertures are circular.

3. The shroud of claim **1**, wherein at least some aperture clusters have a "+" shaped configuration, a staggered configuration, a line configuration, or a double-line configuration.

4. The shroud of claim **1**, wherein at least one aperture cluster is positioned in each of the four quadrants of the elliptical lip section.

5. The shroud of claim **1**, wherein the aperture clusters include a first aperture cluster oriented approximately between 70 degrees and approximately 90 degrees relative to the first axis,

a second aperture cluster oriented between approximately 130 and approximately 175 degrees relative to the first axis,

a third aperture cluster oriented between approximately 160 degrees and approximately 190 degrees relative to the first axis,

a fourth aperture cluster oriented between approximately 185 degrees and approximately 235 degrees relative to the first axis, and

a fifth aperture cluster oriented between approximately 270 degrees and approximately 315 degrees relative to the first axis.

6. The shroud of claim **5**, wherein the first aperture cluster and the fifth aperture cluster are positioned on the elliptical lip section symmetrically with respect to the first axis.

7. The shroud of claim **5**, wherein the second aperture cluster, the third aperture cluster, and the fourth aperture cluster are positioned on the elliptical lip section asymmetrically with respect to the first axis.

8. The shroud of claim **1**, wherein the aperture clusters comprise a first aperture cluster, a second aperture cluster, a third aperture cluster, a fourth aperture cluster, and a fifth aperture cluster, the first aperture cluster being oriented between approximately 40 degrees and approximately 70 degrees relative to the second aperture cluster, the second aperture cluster being oriented between approximately 5 degrees and approximately 35 degrees relative to the aperture third cluster, the third aperture cluster being oriented between approximately 50 degrees and approximately 80 degrees relative to the fourth aperture cluster **816***d*, the fourth aperture cluster being oriented between approximately 40 degrees and approximately 70 degrees relative to the fifth aperture cluster, and the fifth aperture cluster being oriented at between about 140 degrees and approximately 180 degrees relative to the first aperture cluster.

9. A shroud for a cooling fan, the fan being positionable within the chassis of an off-highway machine, the shroud comprising:

an inlet;

an outlet; and

an elliptical lip section positioned at the outlet, the elliptical lip section including a first planar face and a second planar face facing away from the first planar face, the second planar face having a centroid,

wherein a plane coincident with the second planar face includes a first axis parallel to the second and fourth sides of the inlet and a second axis perpendicular to the first axis, both the first axis and the second axis passing through the centroid,

wherein a plurality of apertures extending through the elliptical lip section are configured to at least partially relieve a pressure gradient generated by a portion of the elliptical lip section, and

wherein each aperture in the plurality of apertures is arranged in aperture clusters, at least two aperture clusters being spaced at least 30 degrees away from each other.

10. The shroud of claim **9**, wherein the first axis and the second axis together define four quadrants of the elliptical lip section, at least one cluster of the plurality of clusters being positioned in each quadrant of the four quadrants.

11. A shroud for a cooling fan, the fan positionable within the chassis of an off-highway machine, the shroud comprising:

an inlet having a first side, a second side, a third side, and a fourth side;

an outlet; and

an elliptical lip section positioned at the outlet, the elliptical lip section including a first planar face and a second planar face facing away from the first planar face, the second planar face having a centroid,

wherein a plane coincident with the second planar face includes a first axis parallel to the second and fourth sides of the inlet and a second axis perpendicular to the first axis, both the first axis and the second axis passing through the centroid, wherein the first and second axes together divide the elliptical lip section into four quadrants,

wherein a plurality of apertures extend through the elliptical lip section, at least one aperture of the plurality of apertures positioned in each quadrant of the four quadrants of the elliptical lip section, and

wherein the apertures are circular.

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